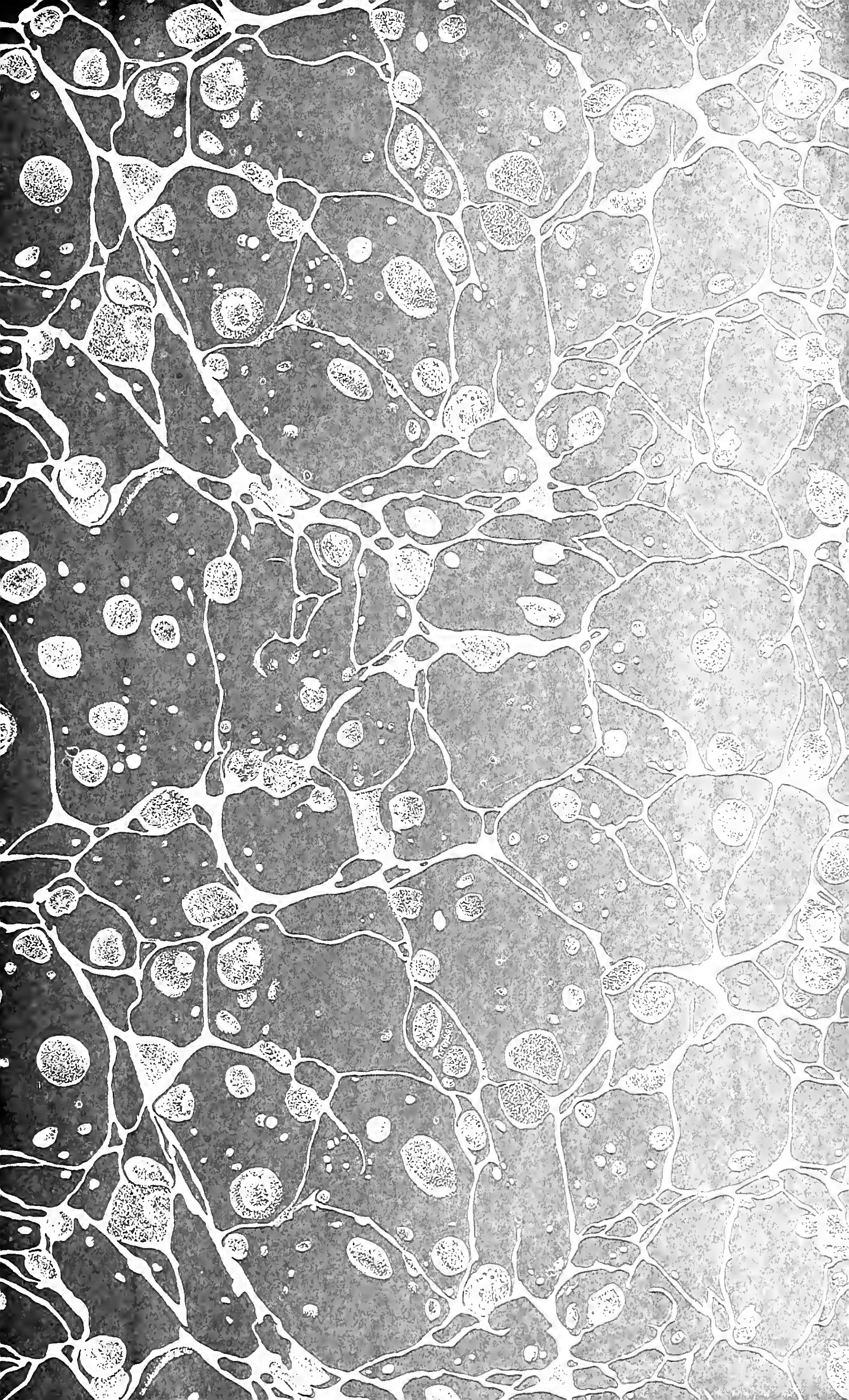

SMITHSONIAN

MISCELLANEOUS COLLECTIONS

VOL. 88

"EVERY MAN IS A VALUABLE MEMBER OF SOCIETY WHO, BY HIS OBSERVATIONS, RESEARCHES, AND EXPERIMENTS, PROCURES KNOWLEDGE FOR MEN"—SMITHSON

(PUBLICATION 3240)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1934

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

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The present series, entitled "Smithsonian Miscellaneous Collections," is intended to embrace all the octavo publications of the Institution, except the Annual Report. Its scope is not limited, and the volumes thus far issued relate to nearly every branch of science. Among these various subjects zoology, bibliography, geology, mineralogy, anthropology, and astrophysics have predominated.

The Institution also publishes a quarto series entitled "Smithsonian Contributions to Knowledge." It consists of memoirs based on extended original investigations, which have resulted in important additions to knowledge.

C. G. ABBOT,
Secretary of the Smithsonian Institution.

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SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 88
(WHOLE VOLUME)

SMITHSONIAN PHYSICAL TABLES

EIGHTH REVISED EDITION

PREPARED BY
FREDERICK E. FOWLE
ASSOCIATE PHYSICIST, SMITHSONIAN ASTROPHYSICAL OBSERVATORY

(PUBLICATION 3171)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1933

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BALTIMORE, MD., U. S. A.

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In connection with the system of meteorological observations established by the Smithsonian Institution about 1850, a series of meteorological tables was compiled by Dr. Arnold Guyot, at the request of Secretary Henry, and the first edition was published in 1852. Though primarily designed for meteorological observers reporting to the Smithsonian Institution, the tables were so widely used by physicists that it seemed desirable to recast the work entirely. It was decided to publish three sets of tables, each representative of the latest knowledge in its field, and independent of one another, but forming a homogeneous series. The first of the new series, Meteorological Tables, was published in 1893, the second, Geographical Tables, in 1894, and the third, Physical Tables, in 1896. In 1909 and 1922, respectively, two further volumes were added, so that the series now comprises: Smithsonian Meteorological Tables, Smithsonian Geographical Tables, Smithsonian Physical Tables, Smithsonian Mathematical Tables, Smithsonian Mathematical Formulae.

The 14 years which had elapsed in 1910 since the publication of the first edition of the Physical Tables, prepared by Prof. Thomas Gray, made imperative a radical revision for the fifth and sixth revised editions published in 1910 and 1914. The latter edition was reprinted thrice. The seventh revision was issued in 1919 and was reprinted thrice. The present eighth edition results from a further extensive revision.

Inconsistencies that will be noted in minor points of style, such as abbreviations, etc., arise from the fact that many of the tables are printed from electrotype plates; to change them to agree with present usages would involve too great expense.

Charles G. Abbot,
Secretary, Smithsonian Institution.

March, 1932.

PREFACE TO 8TH REVISED EDITION

The present edition of the Smithsonian Physical Tables entails a considerable enlargement. Besides the insertion of new data in the older tables, about 270 new ones have been added. Their scope has been further broadened to include many new tables relating to astrophysics, geophysics, meteorology, geochemistry, atmospheric electricity, wireless, molecular and atomic data, etc.

Many suggestions and data have been received: from the Bureau of Standards, the Coast and Geodetic Survey (magnetic data), the Geophysical Laboratory, Naval Research Laboratory, Department of Terrestrial Magnetism, Harvard College Observatory, Eastman Kodak Co. (photographic data), National Research Council (International Critical Tables); from Messrs. Adams, White (Geophysical Laboratory), R. T. Birge, Briggs, Dellinger, Deming (Bureau of Chemistry and Soils), Dorsey (I. C. T.), Fleming, Forsythe, Hulburt, Lovejoy and Loomis (Eastman Kodak Co.), Kimball, Menzel, van Maanen, Russell, Shapley, St. John, Wells, Wherry, and many others whose names generally will be found with the corresponding data furnished. To all these we are indebted.

The changes in the domain of physics and allied branches have been so radical and extensive that it has been difficult to do justice to the advances. Further, it has been deemed essential to keep this volume in handy size, referring the reader to the more extensive International Critical Tables or to Landolt-Börnstein's Physikalisch-chemische Tabellen for more extensive data. It has been inadvisable to delay the tables for revision in many places. We will be grateful for criticisms, the notification of errors, and new data.

FREDERICK EUGENE FOWLE.

ASTROPHYSICAL OBSERVATORY,
SMITHSONIAN INSTITUTION,
March, 1932.

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INTRODUCTION

UNITS OF MEASUREMENT

The quantitative measure of anything is expressed by two factors, — one, a certain definite amount of the kind of physical quantity measured, called the unit, the other, the number of times this unit is taken. A distance is stated as 5 meters. The purpose in such a statement is to convey an idea of this distance in terms of some familiar or standard unit distance. Similarly quantity of matter is referred to as so many grams; of time, as so many seconds, or minutes, or hours.

The numerical factor definitive of the magnitude of any quantity must depend on the size of the unit in terms of which the quantity is measured. For example, let the magnitude factor be 5 for a certain distance when the mile is used as the unit of measurement. A mile equals 1760 yards or 5280 feet. The numerical factor evidently becomes 8800 and 26400, respectively, when the yard or the foot is used as the unit. Hence, to obtain the magnitude factor for a quantity in terms of a new unit, multiply the old magnitude factor by the ratio of the magnitudes of the old and new units; that is, by the number of the new units required to make one of the old.

The different kinds of quantities measured by physicists fall fairly definitely into two classes. In one class the magnitudes may be called extensive, — in the other, intensive. To decide to which class a quantity belongs, it is often helpful to note the effect of the addition of two equal quantities of the kind in question. If twice the quantity results, then the quantity has extensive (additive) magnitude. For instance, two pieces of platinum, each weighing 5 grams, added together, weigh 10 grams; on the other hand, the addition of one piece of platinum at 100° C to another at 100° C does not result in a system at 200° C. Volume, entropy, energy may be taken as typical of extensive, — density, temperature and magnetic permeability, of intensive magnitudes.

The measurement of quantities having extensive magnitude is a comparatively direct process. Those having intensive magnitude must be correlated with phenomena which may be measured extensively. In the case of temperature, a typical quantity with intensive magnitude, various methods of measurement have been devised, such as the correlation of magnitudes of temperature with the varying lengths of a thread of mercury.

Fundamental Units. — It is desirable that the fewest possible fundamental unit quantities should be chosen. Simplicity should regulate the choice, — simplicity 1st, psychologically, in that they should be easy to grasp mentally, and 2nd, physically, in permitting as straightforward and simple definition as

possible of the complex relationships involving them. Further it seems desirable that the units should be extensive in nature. It has been found possible to express all measurable physical quantities in terms of five such units: 1st, geometrical considerations — length, surface, etc., — lead to the need of a length; 2nd, kinematical considerations — velocity, acceleration, etc., — introduce time; 3rd, mechanics — treating of masses instead of immaterial points — introduces matter with the need of a fundamental unit of mass; 4th, electrical, and 5th, thermal considerations require two more such quantities. The discovery of new classes of phenomena may require further additions.

As to the first three fundamental quantities, simplicity and good use sanction the choice of a length, L, a time interval, T, and a mass, M. For the measurement of electrical quantities, good use has sanctioned two fundamental quantities, — the dielectric constant, K, the basis of the "electrostatic" system and the magnetic permeability, μ, the basis of the "electromagnetic" system. Besides these two systems involving electrical considerations, there is in common use a third one called the "international" system which will be referred to later. For the fifth, or thermal fundamental unit, temperature is generally chosen.[1]

Derived Units. — Having selected the fundamental or basic units, — namely, a measure of length, of time, of mass, of permeability or of the dielectric constant, and of temperature, — it remains to express all other units for physical quantities in terms of these. Units depending on powers greater than unity of the basic units are called "derived units." Thus, the unit volume is the volume of a cube having each edge a unit of length. Suppose that the capacity of some volume is expressed in terms of the foot as fundamental unit and the volume number is wished when the yard is taken as the unit. The yard is three times as long as the foot and therefore the volume of a cube whose edge is a yard is $3 \times 3 \times 3$ times as great as that whose edge is a foot. Thus the given volume will contain only 1/27 as many units of volume when the yard is the unit of length as it will contain when the foot is the unit. To transform from the foot as old unit to the yard as new unit, the old volume number must be multiplied by 1/27, or by the ratio of the magnitude of the old to that of the new unit of volume. This is the same rule as already given, but it is usually more convenient to express the transformations in terms of the fundamental units directly. In the present case, since, with the method of measurement here adopted, a volume number is the cube of a length-number, the ratio of two units of volume is the cube of the ratio of the intrinsic values of the two units of length. Hence, if l is the ratio of the magnitude of the old to that of the new unit of length, the ratio of the corresponding units of volume is l^3. Similarly the ratio of two units of area would be l^2, and so on for other quantities.

[1] Because of its greater psychological and physical simplicity, and the desirability that the unit chosen should have extensive magnitude, it has been proposed to choose as the fourth fundamental quantity, a quantity of electrical charge, e. The standard unit of electrical charge would then be the electronic charge. For thermal needs, entropy has been proposed. While not generally so psychologically easy to grasp as temperature, entropy is of fundamental importance in thermodynamics and has extensive magnitude. (R. C. Tolman, The Measurable Quantities of Physics, Physical Review, 9, p. 237, 1917.)

CONVERSION FACTORS AND DIMENSIONAL FORMULAE

For the ratios of length, mass, time, temperature, dielectric constant and permeability units the small bracketed letters, $[l]$, $[m]$, $[t]$, $[\theta]$, $[k]$, and $[\mu]$ will be adopted. These symbols will always represent simple numbers, but the magnitude of the number will depend on the relative magnitudes of the units the ratios of which they represent. When the values of the numbers represented by these small bracketed letters as well as the powers of them involved in any particular unit are known, the factor for the transformation is at once obtained. Thus, in the above example, the value of l was $1/3$, and the power involved in the expression for volume was 3; hence the factor for transforming from cubic feet to cubic yards was l^3 or $1/3^3$ or $1/27$. These factors will be called *conversion factors.*

To find the symbolic expression for the conversion factor for any physical quantity, it is sufficient to determine the degree to which the quantities length, mass, time, etc., are involved. Thus a velocity is expressed by the ratio of the number representing a length to that representing an interval of time, or $[L/T]$, and acceleration by a velocity number divided by an interval-of-time number, or $[L/T^2]$, and so on, and the corresponding ratios of units must therefore enter in precisely the same degree. The factors would thus be for the just stated cases, $[l/t]$ and $[l/t^2]$. Equations of the form above given for velocity and acceleration which show the dimensions of the quantity in terms of the fundamental units are called *dimensional equations.* Thus $[E]=[ML^2T^{-2}]$ will be found to be the dimensional equation for energy, and $[ML^2T^{-2}]$ the dimensional formula for it. These expressions will be distinguished from the conversion factors by the use of bracketed capital letters.

In general, if we have an equation for a physical quantity,

$$Q = CL^aM^bT^c,$$

where C is a constant and L, M, T represent length, mass, and time in terms of one set of units, and it is desired to transform to another set of units in terms of which the length, mass, and time are $L_{\prime}$, $M_{\prime}$, $T_{\prime}$, we have to find the value of $L_{\prime}/L$, $M_{\prime}/M$, $T_{\prime}/T$, which, in accordance with the convention adopted above, will be l, m, t, or the ratios of the magnitudes of the old to those of the new units.

Thus $L_{\prime} = Ll$, $M_{\prime} = Mm$, $T_{\prime} = Tt$, and if $Q_{\prime}$ be the new quantity number,

$$\begin{aligned} Q_{\prime} &= CL_{\prime}^aM_{\prime}^bT_{\prime}^c, \\ &= CL^al^aM^bm^bT^ct^c = Ql^am^bt^c, \end{aligned}$$

or the conversion factor is $[l^am^bt^c]$, a quantity precisely of the same form as the dimension formula $[L^aM^bT^c]$.

Dimensional equations are useful for checking the validity of physical equations. Since physical equations must be homogeneous, each term appearing in them must be dimensionally equivalent. For example, the distance moved by a uniformly accelerated body is $s = v_0t + \frac{1}{2}at^2$. The corresponding dimensional equation is $[L]=[(L/T)T]+[(L/T^2)T^2]$, each term reducing to $[L]$.

Dimensional considerations may often give insight into the laws regulating physical phenomena.[1] For instance Lord Rayleigh, in discussing the intensity

[1] See "On Physically Similar Systems; Illustrations of the Use of Dimensional Equations." E. Buckingham, Physical Review, (2) 4, 345, 1914; also Phil. Mag. 42, 696, 1921.

of light scattered from small particles, in so far as it depends upon the wave length, reasons as follows:[1]

"The object is to compare the intensities of the incident and scattered ray; for these will clearly be proportional. The number (i) expressing the ratio of the two amplitudes is a function of the following quantities:— T, the volume of the disturbing particle; r, the distance of the point under consideration from it; λ, the wave length; b, the velocity of propagation of light; D and D', the original and altered densities: of which the first three depend only on space, the fourth on space and time, while the fifth and sixth introduce the consideration of mass. Other elements of the problem there are none, except mere numbers and angles, which do not depend upon the fundamental measurements of space, time, and mass. Since the ratio i, whose expression we seek, is of no dimensions in mass, it follows at once that D and D' occur only under the form D: D', which is a simple number and may therefore be omitted. It remains to find how i varies with T, r, λ, b.

"Now, of these quantities, b is the only one depending on time; and therefore, as i is of no dimensions in time, b cannot occur in its expression. We are left, then, with T, r, and λ; and from what we know of the dynamics of the question, we may be sure that i varies directly as T and inversely as r, and must therefore be proportional to $T \div \lambda^2 r$, T being of three dimensions in space. In passing from one part of the spectrum to another λ is the only quantity which varies, and we have the important law:

"When light is scattered by particles which are very small compared with any of the wave lengths, the ratio of the amplitudes of the vibrations of the scattered and incident light varies inversely as the square of the wave length, and the intensity of the lights themselves as the inverse fourth power."

The dimensional and conversion-factor formulae for the more commonly occurring derived units will now be developed.

GEOMETRICAL AND MECHANICAL UNITS

Area is referred to a unit square whose side is the unit of length. The area of a surface is expressed as

$$S = CL^2,$$

where the constant C depends on the contour of the surface and L is a linear dimension. If the surface is a square and L the length of a side, C is unity; if a circle and L its diameter, C is $\pi/4$. The dimensional formula is therefore $[L^2]$ and the conversion factor $[l^2]$. (Since the conversion factors are always of the same dimensions as the dimensional formulae they will be omitted in the subsequent discussions. A table of them will be found on page 3.)

Volume is referred to a unit cube whose edge is the unit of length. The volume of a body is expressed as

$$V = CL^3.$$

The constant C depends on the shape of the bounding surfaces. The dimensional formula is $[L^3]$.

Density is the quantity of matter per unit volume. The dimensional formula is $[M/V]$ or $[ML^{-3}]$.

Ex.—The density of a body is 150 pd. per cu. ft.: required the density in grains per cu. in. Here m, the number of grains in a pd., = 7000; l, the number of in. in a ft., = 12; $ml^{-3} = 7000/12^3 = 4.051$. The density is $150 \times 4.051 = 607.6$ grains/cu. in.

The specific gravity of a body is the ratio of a density to the density of a standard substance. The dimensional formula and conversion factor are both unity.

[1] Philos. Mag., (4) 41, p. 107, 1871. See also Robertson, Dimensional analysis, Gen. Elec. Rev., 33, 207, 1930.

Velocity, v, of a body is dL/dt, or the ratio of a length to a time. The dimensional formula is $[LT^{-1}]$.

Angle is measured by the ratio of the length of an arc to its radius. The dimensional formula is unity.

Angular Velocity is the ratio of the angle described in a given time to that time. The dimensional formula is $[T^{-1}]$.

Linear Acceleration is the rate of change of velocity or $a = dv/dt$. The dimensional formula is $[VT^{-1}]$ or $[LT^{-2}]$.

Ex. — A body acquires velocity at a uniform rate and at the end of one minute moves at the rate of 20 kilometers per hour: what is the acceleration in centimeters per second per second? Since the velocity gained was 20 km per hour in one minute, the acceleration was 1200 km per hour per hour. $l = 100000$, $t = 3600$, $lt^{-2} = 100000/3600^2 = 0.00771$; the acceleration $= .00771 \times 1200 = 9.26$ cm/sec.

Angular Acceleration is rate of change of angular velocity. The dimensional formula is [(angular velocity)/T] or $[T^{-2}]$.

Momentum, the quantity of motion in the Newtonian sense, is measured by the product of the mass and velocity of the body. The dimensional formula is $[MV]$ or $[MLT^{-1}]$.

Moment of Momentum of a body with reference to a point is the product of its momentum by the distance of its line of motion from the point. The dimensional formula is $[ML^2T^{-1}]$.

Moment of Inertia of a body round an axis is expressed by the formula Σmr^2, where m is the mass of any particle of the body and r its distance from the axis. The dimensional formula for the sum is the same as for each element and is $[ML^2]$.

Angular Momentum of a body is the product of its moment of inertia and angular velocity. The dimensional formula is $[ML^2T^{-1}]$.

Force is measured by the rate of change of momentum it can produce. The dimensional formulae for force and "time rate of change of momentum" are therefore the same, the ratio of a momentum to a time $[MLT^{-2}]$.

Ex. — When mass is expressed in lbs., length in ft., and time in secs., the unit force is called the poundal. When grams, cms, and secs. are the corresponding units, the unit of force is called the dyne. Find the number of dynes in 25 poundals. Here $m = 453.59$, $l = 30.48$, $t = 1$; $mlt^{-2} = 453.59 \times 30.48 = 13825$ nearly. The number of dynes is $13825 \times 25 = 345625$ approximately.

Moment of Couple, Torque, or Twisting Motive can be expressed as the product of a force and a length. The dimensional formula is $[FL]$ or $[ML^2T^{-2}]$.

Intensity of Stress is the ratio of the total stress to the area over which the stress is distributed. The dimensional formula is $[FL^{-2}]$ or $[ML^{-1}T^{-2}]$.

Intensity of Attraction, or **"Force at a Point,"** is the force of attraction per unit mass on a body placed at the point. The dimensional formula is $[FM^{-1}]$ or $[LT^{-2}]$, the same as acceleration.

Absolute Force of a Center of Attraction, or "**Strength of a Center,**" is the intensity of force at unit distance from the center, and is the force per unit mass at any point multiplied by the square of the distance from the center. The dimensional formula is $[FL^2M^{-1}]$ or $[L^3T^{-2}]$.

Modulus of Elasticity is the ratio of stress intensity to percentage strain. The dimensional of percentage strain, a length divided by a length, is unity. Hence the dimensional formula of a modulus of elasticity is that of stress intensity $[ML^{-1}T^{-2}]$.

Work is done by a force when the point of application of the force, acting on a body, moves in the direction of the force. It is measured by the product of the force and the displacement. The dimensional formula is $[FL]$ or $[ML^2T^{-2}]$.

Energy. — The work done by the force produces either a change in the velocity of the body or a change of its shape or configuration, or both. In the first case it produces a change of kinetic energy, in the second, of potential energy. The dimensional formulae of energy and work, representing quantities of the same kind, are identical $[ML^2T^{-2}]$.

Resilience is the work done per unit volume of a body in distorting it to the elastic limit or in producing rupture. The dimensional formula is $[ML^2T^{-2}L^{-3}]$ or $[ML^{-1}T^{-2}]$.

Power or Activity is the time rate of doing work, or if W represents work and P power, $P = dw/dt$. The dimensional formula is $[WT^{-1}]$ or $[ML^2T^{-3}]$, or for problems in gravitation units more conveniently $[FLT^{-1}]$, where F stands for the force factor.

Exs. — Find the number of gram-cms in one ft.-pd. Here the units of force are the attraction of the earth on the pound and the gram of matter. (In problems like this the terms "grams" and "pd." refer to force and not to mass.) The conversion factor is $[fl]$, where f is 453.59 and l is 30.48. The answer is $453.59 \times 30.48 = 13825$.

Find the number of ft.-poundals in 1000000 cm-dynes. Here $m = 1/453.59$, $l = 1/30.48$, $t = 1$; $ml^2t^{-2} = 1/453.59 \times 30.48^2$, and $10^6ml^2t^{-2} = 10^6/453.59 \times 30.48^2 = 2.373$.

If gravity produces an acceleration of 32.2 ft./sec./sec., how many watts are required to make one horsepower? One horsepower is 550 ft.-pds. per sec., or $550 \times 32.2 = 17710$ ft.-poundals per second. One watt is 10^7 ergs per sec., that is, 10^7 dyne-cms per sec. The conversion factor is $[ml^2t^{-3}]$, where m is 453.59, l is 30.48, and t is 1, and the result has to be divided by 10^7, the number of dyne-cms per sec. in the watt. $17710\, ml^2t^{-3}/10^7 = 17710 \times 453.59 \times 30.48^2/10^7 = 746.3$.

HEAT UNITS

Quantity of Heat, measured in dynamical units, has the same dimensions as energy $[ML^2T^{-2}]$. Ordinary measurements, however, are made in *thermal units*, that is, in terms of the amount of heat required to raise the temperature of a unit mass of water one degree of temperature at some stated temperature. This involves the unit of mass and some unit of temperature. If we denote temperature numbers by Θ, the dimensional formula for quantity of heat, H, will be $[M\Theta]$. Unit volume is sometimes used instead of unit mass in the measurement of heat, the units being called *thermometric units*. The dimensional formula now changed by the substitution of volume for mass is $[L^3\Theta]$.

Specific Heat is the relative amount of heat, compared with water as standard substance, required to raise unit mass of different substances one degree in temperature and is a simple number.

Coefficient of Thermal Expansion of a substance is the ratio of the change of length per unit length (linear), or change of volume per unit volume (voluminal), to the change of temperature. These ratios are simple numbers, and the change of temperature varies inversely as the magnitude of the unit of temperature. The dimensional formula is $[\Theta^{-1}]$.

Thermal Conductivity, or **Specific Conductance,** is the quantity of heat, H, transmitted per unit of time per unit of surface per unit of temperature gradient. The equation for conductivity is therefore $K = H/L^2T\Theta/L$, and the dimensional formula $[H/\Theta LT] = [ML^{-1}T^{-1}]$ in thermal units. In thermometric units the formula becomes $[L^2T^{-1}]$, which properly represents diffusivity, and in dynamical units $[MLT^{-3}\Theta^{-1}]$.

Thermal Capacity is mass times the specific heat. The dimensional formula is $[M]$.

Latent Heat is the quantity of heat required to change the state of a body divided by the quantity of matter. The dimensional formula is $[M\Theta/M]$ or $[\Theta]$; in dynamical units it is $[L^2T^{-2}]$.

NOTE. — When Θ is given the dimensional formula $[L^2T^{-2}]$, the formulae in thermal and dynamical units are identical.

Joule's Equivalent, J, is connected with the quantity of heat by the equation $ML^2T^{-2} = JH$ or $JM\Theta$. The dimensional formula of J is $[L^2T^{-2}\Theta^{-1}]$. In dynamical units J is a simple number.

Entropy of a body is directly proportional to the quantity of heat it contains and inversely proportional to its temperature. The dimensional formula is $[M\Theta/\Theta]$ or $[M]$. In dynamical units the formula is $[ML^2T^{-2}\Theta^{-1}]$.

EXS. — Find the relation between the British thermal unit, the large or kilogram-calorie and the small or gram-calorie, sometimes called the "therm." Referring all the units to the same temperature of the standard substance, the *British thermal unit* is the amount of heat required to warm one pound of water 1° F., the *large calorie*, 1 kilogram of water, 1° C, the *small calorie* or *therm*, 1 gram, 1° C. (1) To find the number of kg-cals. in one British thermal unit. $m = .45359$, $\theta = 5/9$; $m\theta = .45359 \times 5/9 = .25199$. (2) To find the number therms in one kg-cal. $m = 1000$, and $\theta = 1$; $m\theta = 1000$. (3) Hence the number of small calories or therms in one British thermal unit is $1000 \times .25199 = 251.99$.

ELECTRIC AND MAGNETIC UNITS

A system of units of electric and magnetic quantities requires four fundamental quantities. A system in which length, mass, and time constitute three of the fundamental quantities is known as an "absolute" system. There are two absolute systems of electric and magnetic units. One is called the electrostatic, in which the fourth fundamental quantity is the dielectric constant, and one is called the electromagnetic, in which the fourth fundamental quantity is magnetic permeability. Besides these two systems there will be described a third in common use called the "international" system.

In the electrostatic system, unit quantity of electricity, Q, is the quantity which exerts unit mechanical force upon an equal quantity a unit distance from it in a vacuum. From this definition the dimensions and the units of all the other electric and magnetic quantities follow through the equations of the mathematical theory of electromagnetism. The mechanical force between two quantities of electricity in any medium is

$$F = \frac{QQ'}{Kr^2},$$

where K is the dielectric constant, characteristic of the medium, and r the distance between the two points at which the quantities Q and Q' are located. K is the fourth quantity entering into dimensional expressions in the electrostatic system. Since the dimensional formula for force is $[MLT^{-2}]$, that for Q is $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}]$.

The electromagnetic system is based upon the unit of the magnetic pole strength. The dimensions and the units of the other quantities are built up from this in the same manner as for the electrostatic system. The mechanical force between two magnetic poles in any medium is

$$F = \frac{mm'}{\mu r^2},$$

in which μ is the permeability of the medium and r is the distance between two poles having the strengths m and m'. μ is the fourth quantity entering into dimensional expressions in the electromagnetic system. It follows that the dimensional expression for magnetic pole strength is $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}\mu^{\frac{1}{2}}]$.

The symbols K and μ are sometimes omitted in the dimensional formulae so that only three fundamental quantities appear. There are a number of objections to this. Such formulae give no information as to the relative magnitudes of the units in the two systems. The omission is equivalent to assuming some relation between mechanical and electrical quantities, or to a mechanical explanation of electricity. Such a relation or explanation is not known.

The properties K and μ are connected by the equation $1/\sqrt{K\mu} = v$, where v is the velocity of an electromagnetic wave. For empty space or for air, K and μ being measured in the same units, $1/\sqrt{K\mu} = c$, where c is the velocity of light in vacuo, 3×10^{10} cm per sec. It is sometimes forgotten that the omission of the dimensions of K or μ is merely conventional. For instance, magnetic field intensity and magnetic induction apparently have the same dimensions when μ is omitted. This results in confusion and difficulty in understanding the theory of magnetism. The suppression of μ has also led to the use of the "centimeter" as a unit of capacity and of inductance; neither is physically the same as length.

ELECTROSTATIC SYSTEM

Quantity of Electricity has the dimensional formula $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}]$, as shown above.

Electric Surface Density of an electrical distribution at any point on a surface is measured by the quantity per unit area. The dimensional formula is the ratio of the formulae for quantity of electricity and for area or $[M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}K^{\frac{1}{2}}]$.

Electric Field Intensity is measured by the ratio of the force on a quantity of electricity at a point to the quantity of electricity. The dimensional formula is therefore the ratio of the formulae for force and electric quantity or $[MLT^{-2}/M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}]$ or $[M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}]$.

Electric Potential and Electromotive Force. — Change of potential is proportional to the work done per unit of electricity in producing the change. The dimensional formula is the ratio of the formulae for work and electrical quantity or $[ML^2T^{-2}/M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}]$ or $[M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}]$.

Capacity of an Insulated Conductor is proportional to the ratio of the quantity of electricity in a charge to the potential of the charge. The dimensional formula is the ratio of the two formulae for electric quantity and potential or $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}/M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}]$ or $[LK]$.

Specific Inductive Capacity is the ratio of the inductive capacity of the substance to that of a standard substance and therefore is a number.

Electric Current is quantity of electricity flowing past a point per unit of time. The dimensional formula is the ratio of the formulae for electric quantity and for time or $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}/T]$ or $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}K^{\frac{1}{2}}]$.

Electrical Conductivity, like the corresponding term for heat, is quantity per unit area per unit potential gradient per unit of time. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}/L^2(M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}/L)T]$ or $[T^{-1}K]$.

Resistivity is the reciprocal of conductivity. The dimensional formula is $[TK^{-1}]$.

Conductance of any part of an electric circuit, not containing a source of electromotive force, is the ratio of the current flowing through it to the difference of potential between its ends. The dimensional formula is the ratio of the formulae for current and potential or $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}K^{\frac{1}{2}}/M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}]$ or $[LT^{-1}K]$.

Resistance is the reciprocal of conductance. The dimensional formula is $[L^{-1}TK^{-1}]$.

Exs. — Find the factor for converting quantity of electricity expressed in ft.-grain-sec. units to the same expressed in c.g.s. units. The formula is $[m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-1}k^{\frac{1}{2}}]$, in which $m = 0.0648$, $l = 30.48$, $t = 1$, $k = 1$; the factor is $0.0648^{\frac{1}{2}} \times 30.48^{\frac{3}{2}}$, or 42.8.

Find the factor required to convert electric potential from mm-mg-sec. units to c.g.s. units. The formula is $[m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}k^{-\frac{1}{2}}]$, in which $m = 0.001$, $l = 0.1$, $t = 1$, $k = 1$; the factor is $0.001^{\frac{1}{2}} \times 0.1^{\frac{1}{2}}$, or 0.01.

Find the factor required to convert electrostatic capacity from ft.-grain-sec. and specific inductive capacity 6 units to c.g.s. units. The formula is $[lk]$ in which $l = 30.48$, $k = 6$; the factor is 30.48×6, or 182.88.

ELECTROMAGNETIC SYSTEM

Many of the magnetic quantities are analogues of certain electric quantities. The dimensions of such quantities in the electromagnetic system differ from those of the corresponding electrostatic quantities in the electrostatic system only in the substitution of permeability μ for K.

Magnetic Pole Strength or **Quantity of Magnetism** has already been shown to have the dimensional formula $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}\mu^{\frac{1}{2}}]$.

Magnetic Flux characterizes the magnetized state of a magnetic circuit. Through a surface inclosing a magnetic pole it is proportional to the magnetic pole strength. The dimensional formula is that for magnetic pole strength.

Magnetic Field Intensity or **Magnetizing Force** is the ratio of the force on a magnetic pole placed at the point and the magnetic pole strength. The dimensional formula is therefore the ratio of the formulae for a force and magnetic quantity, or $[MLT^{-2}/M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}\mu^{\frac{1}{2}}]$ or $[M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}\mu^{-\frac{1}{2}}]$.

Magnetic Potential or **Magnetomotive Force** at a point is measured by the work which is required to bring unit quantity of positive magnetism from zero potential to the point. The dimensional formula is the ratio of the formulae for work and magnetic quantity, $[ML^2T^{-2}/M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}\mu^{\frac{1}{2}}]$ or $[M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}\mu^{-\frac{1}{2}}]$.

Magnetic Moment is the product of the pole strength by the length of the magnet. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{5}{2}}T^{-1}\mu^{\frac{1}{2}}]$.

Intensity of Magnetization of any portion of a magnetized body is the ratio of the magnetic moment of that portion and its volume. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{5}{2}}T^{-1}\mu^{\frac{1}{2}}/L^3]$ or $[M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}\mu^{\frac{1}{2}}]$.

Magnetic Induction is the magnetic flux per unit of area taken perpendicular to the direction of the magnetic flux. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}\mu^{\frac{1}{2}}/L^2]$ or $[M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}\mu^{\frac{1}{2}}]$.

Magnetic Susceptibility is the ratio of intensity of magnetization produced and the intensity of the magnetic field producing it. The dimensional formula is $[M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}\mu^{\frac{1}{2}}/M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}\mu^{-\frac{1}{2}}]$ or $[\mu]$.

Current, I, flowing in circle, radius r, creates magnetic field at its center, $2\pi I/r$. Dimensional formula is product of formulae for magnetic field intensity and length or $[M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}\mu^{-\frac{1}{2}}]$.

Quantity of Electricity is the product of the current and time. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{1}{2}}\mu^{-\frac{1}{2}}]$.

Electric Potential, or **Electromotive Force,** as in the electrostatic system, is the ratio of work to quantity of electricity. The dimensional formula is $[ML^2T^{-2}/M^{\frac{1}{2}}L^{\frac{1}{2}}\mu^{-\frac{1}{2}}]$ or $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}\mu^{\frac{1}{2}}]$.

Electrostatic Capacity is the ratio of quantity of electricity to difference of potential. The dimensional formula is $[L^{-1}T^2\mu^{-1}]$.

Resistance of a Conductor is the ratio of the difference of potential between its ends and the constant current flowing. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}\mu^{\frac{1}{2}}/M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}\mu^{-\frac{1}{2}}]$ or $[LT^{-1}\mu]$.

Conductance is the reciprocal of resistance, and the dimensional formula is $[L^{-1}T\mu^{-1}]$.

Conductivity is the quantity of electricity transmitted per unit area per unit potential gradient per unit of time. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{1}{2}}\mu^{-\frac{1}{2}}/L^2(M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}\mu^{\frac{1}{2}}/L)\,T]$ or $[L^{-2}T\mu^{-1}]$.

Resistivity is the reciprocal of conductivity as just defined. The dimensional formula is $[L^2T^{-1}\mu]$.

Self-inductance is for any circuit the electromotive force produced in it by unit rate of variation of the current through it. The dimensional formula is the product of the formulae for electromotive force and time divided by that for current or $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}\mu^{\frac{1}{2}} \times T \div M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}\mu^{-\frac{1}{2}}]$ or $[L\mu]$.

Mutual Inductance of two circuits is the electromotive force produced in one per unit rate of variation of the current in the other. The dimensional formula is the same as for self-inductance.

Electric Field Intensity is the ratio of electric potential or electromotive force and length. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-2}\mu^{\frac{1}{2}}]$.

Magnetic Reluctance is the ratio of magnetic potential difference to magnetic flux. The dimensional formula is $[L^{-1}\mu^{-1}]$.

Thermoelectric Power is measured by the ratio of electromotive force and temperature. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}\mu^{\frac{1}{2}}\Theta^{-1}]$.

Coefficient of Peltier Effect is measured by the ratio of the quantity of heat and quantity of electricity. The dimensional formula is $[ML^2T^{-2}/M^{\frac{1}{2}}L^{\frac{1}{2}}\mu^{-\frac{1}{2}}]$ or $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}\mu^{\frac{1}{2}}]$, the same as for electromotive force.

Exs. — Find the factor required to convert intensity of magnetic field from ft.-grain-min. units to c.g.s. units. The formula is $[m^{\frac{1}{2}}l^{-\frac{1}{2}}t^{-1}\mu^{-\frac{1}{2}}]$; $m = 0.0648$, $l = 30.48$, $t = 60$, and $\mu = 1$; the factor is $0.0648^{\frac{1}{2}} \times 30.48^{-\frac{1}{2}}$, or 0.046108.

How many c.g.s. units of magnetic moment make one ft.-grain-sec. unit of the same quantity? The formula is $[m^{\frac{1}{2}}l^{\frac{5}{2}}t^{-1}\mu^{\frac{1}{2}}]$; $m = 0.0648$, $l = 30.48$, $t = 1$, and $\mu = 1$; the number is $0.0648^{\frac{1}{2}} \times 30.48^{\frac{5}{2}}$, or 1305.6.

If the intensity of magnetization of a steel bar is 700 in c.g.s. units, what will it be in mm-mg-sec. units? The formula is $[m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}\mu^{\frac{1}{2}}]$; $m = 1000$, $l = 10$, $t = 1$, $\mu = 1$; the intensity is $700 \times 1000^{\frac{1}{2}} \times 10^{\frac{1}{2}}$, or 70000.

Find the factor required to convert current from c.g.s. units to earth-quadrant-10^{-11} gram-sec. units. The formula is $[m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}\mu^{-\frac{1}{2}}]$; $m = 10^{11}$, $l = 10^{-9}$, $\mu = 1$; the factor is $10^{\frac{11}{2}} \times 10^{-\frac{9}{2}}$, or 10.

Find the factor required to convert resistance expressed in c.g.s. units into the same expressed in earth-quadrant-10^{-11} gram-sec. units. The formula is $[lt^{-1}\mu]$; $l = 10^{-9}$, $t = 1$, $\mu = 1$; the factor is 10^{-9}.

FUNDAMENTAL STANDARDS

The choice of the nature of the fundamental quantities already made does not sufficiently define the system for measurements. Some definite unit or arbitrarily chosen standard must next be taken for each of the fundamental quantities. This fundamental standard should have the qualities of permanence, reproducibility and availability and be suitable for accurate measures. Once chosen and made it is called the primary standard and is generally kept at some central bureau, — for instance, the International Bureau of Weights and Measures at Sèvres, France. A primary standard may also be chosen and made for derived units (e.g., the international ohm standard), when it is simply a standard closely representing the unit and accepted for practical purposes, its value having been fixed by certain measuring processes. Secondary or refer-

ence standards are accurately compared copies, not necessarily duplicates, of the primaries for use in the work of standardizing laboratories and the production of working standards for everyday use.

Standard of Length. — The primary standard of length which now almost universally serves as the basis for physical measurements is the meter. It is defined as the distance between two lines at 0° C on a platinum-iridium bar deposited at the International Bureau of Weights and Measures. This bar is known as the International Prototype Meter, and its length was derived from the "métre des Archives," which was made by Borda. Borda, Delambre, Laplace, and others, acting as a committee of the French Academy, recommended that the standard unit of length should be the ten-millionth part of the length, from the equator to the pole, of the meridian passing through Paris. In 1795 the French Republic passed a decree making this the legal standard of length, and an arc of the meridian extending from Dunkirk to Barcelona was measured by Delambre and Mechain for the purpose of realizing the standard. From the results of that measurement the meter bar was made by Borda. The meter is now defined as above and not in terms of the meridian length; hence subsequent measures of the length of the meridian have not affected the length of the meter.

Standard of Mass. — The primary standard of mass now almost universally used as the basis for physical measurements is the kilogram. It is defined as the mass of a certain piece of platinum-iridium deposited at the International Bureau of Weights and Measures. This standard is known as the International Prototype Kilogram. Its mass is equal to that of the older standard, the "kilogram des Archives," made by Borda and intended to have the same mass as a cubic decimeter of distilled water at the temperature of 4° C.

Copies of the International Prototype Meter and Kilogram are possessed by the various governments and are called National Prototypes.

Standard of Time. — The unit of time universally used is the mean solar second, or the 86400th part of the mean solar day. It is based on the average time of one rotation of the earth on its axis relatively to the sun as a point of reference = 1.002 737 91 sidereal second.

Standard of Temperature. — The standard scale of temperature as adopted by the International Committee of Weights and Measures (1887) depends on the constant-volume hydrogen thermometer. The hydrogen is taken at an initial pressure at 0° C of one meter of mercury, 0° C, sea-level at latitude 45°. The scale is defined by designating the temperature of melting ice as 0° and of condensing steam as 100° under standard atmospheric pressure. This is known as the Centigrade scale (abbreviated C).

A scale independent of the properties of any particular substance, and called the thermodynamic, or absolute scale, was proposed in 1848 by Lord Kelvin. In it the temperature is proportional to the average kinetic energy per molecule of a perfect gas. The temperature of melting ice is taken as 273.18°, that of the boiling point, 373.18°. The scale of the hydrogen thermometer varies from it only in the sense that the behavior of hydrogen departs from that of a perfect gas. It is customary to refer to this scale as the Kelvin scale (abbreviated K.)

NUMERICALLY DIFFERENT SYSTEMS OF UNITS

The fundamental physical quantities which form the basis of a system for measurements have been chosen and the fundamental standards selected and made. Custom has not however generally used these standards for the measurement of the magnitudes of quantities but rather multiples or submultiples of them. For instance, for very small quantities the micron (μ) or one-millionth of a meter is often used. The following table [1] gives some of the systems proposed, all built upon the fundamental standards already described. The centimeter-gram-second (cm-g-sec. or c.g.s.) system proposed by Kelvin is the only one generally accepted.

TABLE I.

PROPOSED SYSTEMS OF UNITS.

	Weber and Gauss	Kelvin c.g.s.	Moon 1891	Giorgi MKS (Prim. Stds.)	France 1914	B. A. Com., 1863	Practical (B. A. Com., 1873)	Strout 1891
Length	mm	cm	dm	m	m	m	10^9 cm	10^9 cm
Mass	mg	g	Kg	Kg	10^6 g	g	10^{-11} g	10^{-9} g
Time	sec.	sec.	$\frac{\text{sec.}}{10}$	sec.	sec.	sec.	sec.	sec.

Further the choice of a set of fundamental physical quantities to form the basis of a system does not necessarily determine how that system shall be used in measurements. In fact, upon any sufficient set of fundamental quantities, a great many different systems of units may be built. The electrostatic and electromagnetic systems are really systems of electric quantities rather than units. They were based upon the relationships $F = QQ'/Kr^2$ and $mm'/\mu r^2$, respectively. Systems of units built upon a chosen set of fundamental physical quantities may differ in two ways: (1) the units chosen for the fundamental quantities may be different; (2) the defining equations by which the system is built may be different.

The electrostatic system generally used is based on the centimeter, gram, second, and dielectric constant of a vacuum. Other systems have appeared, differing from this in the first way, — for instance using the foot, grain and second in place of the centimeter, gram and second. A system differing from it in the second way is that of Heaviside which introduces the factor 4π at different places than is usual in the equations. There are similarly several systems of electromagnetic units in use.

Gaussian Systems. — "The complexity of the interrelations of the units is increased by the fact that not one of the systems is used as a whole, consistently for all electromagnetic quantities. The 'systems' at present used are therefore combinations of certain of the systems of units.

[1] Circular 60 of the Bureau of Standards, Electric Units and Standards, 1916. The subsequent matter in this introduction is based upon this circular.

"Some writers [1] on the theory of electricity prefer to use what is called a Gaussian system, a combination of electrostatic units for purely electrical quantities and electromagnetic units for magnetic quantities. There are two such Gaussian systems in vogue, — one a combination of c.g.s. electrostatic and c.g.s electromagnetic systems, and the other a combination of the two corresponding Heaviside systems.

"When a Gaussian system is used, caution is necessary when an equation contains both electric and magnetic quantities. A factor expressing the ratio between the electrostatic and electromagnetic units of one of the quantities has to be introduced. This factor is the first or second power of c, the number of electrostatic units of electric charge in one electromagnetic unit of the same. There is sometimes a question as to whether electric current is to be expressed in electrostatic or electromagnetic units, since it has both electric and magnetic attributes. It is usually expressed in electrostatic units in the Gaussian system."

It may be observed from the dimensions of K given in Table 1 that $[1/K\mu] = [L^2/T^2]$ which has the dimensions of a square of a velocity. This velocity was found experimentally to be equal to that of light, when K and μ were expressed in the same system of units. Maxwell proved theoretically that $1/\sqrt{K\mu}$ is the velocity of any electromagnetic wave. This was subsequently proved experimentally. When a Gaussian system is used, this equation becomes $c/\sqrt{K\mu} = v$. For the ether $K = 1$ in electrostatic units and $\mu = 1$ in electromagnetic units. Hence $c = v$ for the ether, or the velocity of an electromagnetic wave in the ether is equal to the ratio of the c.g.s. electromagnetic to the c.g.s. electrostatic unit of electric charge. This constant c is of primary importance in electrical theory. Its most probable value is 2.9979×10^{10} centimeters per second.

"Practical" Electromagnetic System. — This electromagnetic system is based upon the units of 10^9 cm, 10^{-11} gram, the sec. and μ of the ether. It is never used as a complete system of units but is of interest as the historical basis of the present International System. The principal quantities are the resistance unit, the ohm = 10^9 c.g.s. units; the current unit, the ampere = 10^{-1} c.g.s. units; and the electromotive force unit, the volt = 10^8 c.g.s. units.

The International Electric Units. — The units used in practical measurements, however, are the "International Units." They were derived from the "practical" system just described, or as the latter is sometimes called, the "absolute" system. These international units are based upon certain concrete standards presently to be defined and described. With such standards electrical comparisons can be more accurately and readily made than could absolute measurements in terms of the fundamental units. Two electric units, the international ohm and the international ampere, were chosen and made as nearly equal as possible to the ohm and ampere of the "practical" or "absolute" system.

[1] For example, A. G. Webster, "Theory of Electricity and Magnetism," 1897; J. H. Jeans, "Electricity and Magnetism," 1911; H. A. Lorentz, "The Theory of Electrons," 1909; and O. W. Richardson, "The Electron Theory of Matter," 1914.

This system of units, sufficiently near to the "absolute" system for the purpose of electrical measurements and as a basis for legislation, was defined as follows:

"1. The *International Ohm* is the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grams in mass, of a constant cross-sectional area and of a length of 106.300 centimeters.

"2. The *International Ampere* is the unvarying electric current which, when passed through a solution of nitrate of silver in water, in accordance with specification II attached to these Resolutions, deposits silver at the rate of 0.00111800 of a gram per second.

"3. The *International Volt* is the electrical pressure which, when steadily applied to a conductor the resistance of which is one international ohm will produce a current of one international ampere.

"4. The *International Watt* is the energy expended per second by an unvarying electric current of one international ampere under the pressure of one international volt."

In accordance with these definitions, a value was established for the electromotive force of the recognized standard of electromotive force, the Weston normal cell, as the result of international coöperative experiments in 1910. The value was 1.0183 international volts at 20° C.

The definitions by the 1908 International Conference supersede certain definitions adopted by the International Electrical Congress at Chicago in 1893. Certain of the units retain their Chicago definitions, however. They are as follows:

"*Coulomb.* As a unit of quantity, the *International Coulomb*, which is the quantity of electricity transferred by a current of one international ampere in one second.

"*Farad.* As a unit of capacity, the *International Farad*, which is the capacity of a condenser, charged to be a potential of one international volt by one international coulomb of electricity.

"*Joule.* As a unit of work, the *Joule*, which is equal to 10^7 units of work in the c.g.s. system, and which is represented sufficiently well for practical use by the energy expended in one second by an international ampere in an international ohm.

"*Henry.* As the unit of induction, the *Henry*, which is the induction in a circuit when the electromotive force induced in this circuit is one international volt, while the inducing current varies at the rate of one ampere per second."

"The choice of the ohm and ampere as fundamental was purely arbitrary. These are the two quantities directly measured in absolute electrical measurements. The ohm and volt have been urged as more suitable for definition in terms of arbitrary standards, because the primary standard of electromotive force (standard cell) has greater simplicity than the primary standard of current (silver voltameter). The standard cell is in fact used, together with resistance standards, for the actual maintenance of the units, rather than the silver voltameter and resistance standards. Again, the volt and ampere have some claim

for consideration for fundamental definition, both being units of quantities more fundamental in electrical theory than resistance."

For all practical purposes the "international" and the "practical" or "absolute" units are the same. Experimental determination of the ratios of the corresponding units in the two systems have been made and the mean results are given in Table 463. These ratios represent the accuracy with which it was possible to fix the values of the international ohm and ampere at the time they were defined (London Conference of 1908). It is unlikely that the definitions of the international units will be changed in the near future to make the agreement any closer. An act approved July 12, 1894, makes the International units as above defined the legal units in the United States of America.

THE STANDARDS OF THE INTERNATIONAL ELECTRICAL UNITS

RESISTANCE

The definition of the international ohm adopted by the London Conference in 1908 is accepted practically everywhere.

Mercury Standards. — Mercury standards conforming to the definition were constructed in England, France, Germany, Japan, Russia and the United States. Their mean resistances agree to about two parts in 100,000. To attain this accuracy, elaborate and painstaking experiments were necessary. Tubes are never quite uniform in cross-section; the accurate measurement of the mass of mercury filling the tube is difficult, partly because of a surface film on the walls of the tube; the greatest refinements are necessary in determining the length of the tube. In the electrical comparison of the resistance with wire standards, the largest source of error is in the filling of the tube. These and other sources of error necessitated a certain uniformity in the setting up of mercury standards and at the London Conference the following specifications were drawn up:

SPECIFICATION RELATING TO MERCURY STANDARDS OF RESISTANCE

The glass tubes used for mercury standards of resistance must be made of a glass such that the dimensions may remain as constant as possible. The tubes must be well annealed and straight. The bore must be as nearly as possible uniform and circular, and the area of cross-section of the bore must be approximately one square millimeter. The mercury must have a resistance of approximately one ohm.

Each of the tubes must be accurately calibrated. The correction to be applied to allow for the area of the cross-section of the bore not being exactly the same at all parts of the tube must not exceed 5 parts in 10,000.

The mercury filling the tube must be considered as bounded by plane surfaces placed in contact with the ends of the tube.

The length of the axis of the tube, the mass of mercury the tube contains, and the electrical resistance of the mercury are to be determined at a temperature as near to 0° C as possible. The measurements are to be corrected to 0° C.

For the purpose of the electrical measurements, end vessels carrying connections for the current and potential terminals are to be fitted on to the tube. These end vessels are to be spherical in shape (of a diameter of approximately four centimeters) and should have cylindrical pieces attached to make connections with the tubes. The outside edge of each end of the tube

is to be coincident with the inner surface of the corresponding end vessel. The leads which make contact with the mercury are to be of thin platinum wire fused into glass. The point of entry of the current lead and the end of the tube are to be at opposite ends of a diameter of the bulb; the potential lead is to be midway between these two points. All the leads must be so thin that no error in the resistance is introduced through conduction of heat to the mercury. The filling of the tube with mercury for the purpose of the resistance measurements must be carried out under the same conditions as the filling for the determination of the mass.

The resistance which has to be added to the resistance of the tube to allow for the effect of the end vessels is to be calculated by the formula

$$A = \frac{0.80}{1063\pi}\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \text{ ohm},$$

where r_1 and r_2 are the radii in millimeters of the end sections of the bore of the tube.

The mean of the calculated resistances of at least five tubes shall be taken to determine the value of the unit of resistance.

For the purpose of the comparison of resistances with a mercury tube the measurements shall be made with at least three separate fillings of the tube.

Secondary Standards. — Secondary standards, derived from the mercury standards and used to give values to working standards, are certain coils of manganin wire kept in the national laboratories. Their resistances are adjusted to correspond to the unit or its decimal multiples or submultiples. The values assigned to these coils are checked from time to time with the similar coils of the other countries. The value now in use is based on the comparison made at the U. S. Bureau of Standards in 1910 and may be called the "1910 ohm." Later measurements on various mercury standards checked the value then used within 2 parts in 100,000. Thus the basis of resistance measurement is maintained not by the mercury standards of a single laboratory, but by all the mercury standards of the various national laboratories; it is furthermore the same in all countries, except for very slight outstanding discrepancies due to the errors of measurement and variations of the standards with time.

Resistance Standards in Practice. — In ordinary measurements, working standards of resistance are usually coils of manganin wire (approximately 84 per cent Cu + 12 per cent Mn + 4 per cent Ni). They are generally used in oil which carries away the heat developed by the current and facilitates regulation and measurement of the temperature. The best type is inclosed in a sealed case for protection against atmospheric humidity. Varying humidity changes the resistance of open coils often to several parts in 10,000 higher in summer than in winter. While sealed 1 ohm and 0.1 ohm coils may remain constant to about 1 part in 100,000.

Absolute Ohm. — The absolute measurement of resistance involves the precise determination of a length and a time (usually an angular velocity) in a medium of unit permeability. Since the dimensional formula of resistance in the electromagnetic system is $[L\mu/T]$, such an absolute measurement gives R not in cm/sec. but in cm $\times\ \mu$/sec. The definitions of the ohm, ampere and volt by the 1908 London conference tacitly assume a permeability equal to unity. The relation of the international ohm to the absolute ohm has been measured in different ways involving revolving coil, revolving disk, and alter-

nate current methods. Probably the most accurate value is that given by Birge (see p. 77).

$$1 \text{ international ohm} = 1.00051 \pm 0.00002 \text{ absolute ohms},$$

or, in other words, while one international ohm is represented by a mercury column 106.300 cm long as specified above, one absolute ohm requires a similar column 106.246 cm long.

CURRENT

The Silver Voltameter. — The silver voltameter is a concrete means of measuring current in accordance with the definition of the international ampere. As used for the realization of the international ampere "it consists of a platinum cathode in the form of a cup holding the silver nitrate solution, a silver anode partly or wholly immersed in the solution, and some means to prevent anode slime and particles of silver mechanically detached from the anode from reaching the cathode. As a standard representing the international ampere, the silver voltameter includes also the chronometer used to measure time. The degree of purity and the mode of preparation of the various parts of the voltameter affect the mass of the deposit. There are numerous sources of error, and the suitability of the silver voltameter as a primary standard of current has been under investigation since 1893. Differences of as much as 0.1 per cent or more may be obtained by different procedures, the larger differences being mainly due to impurities produced in the electrolyte (by filter paper, for instance). Hence, in order that the definition of current be precise, it must be accompanied by *specifications* for using the voltameter."

The original specifications were recognized to be inadequate and an international committee on electrical units and standards was appointed to complete the specifications. It was also recognized that in practice standard cells would replace secondary current standards so that a value must be fixed for the electromotive force of the Weston normal cell. This was attempted in 1910 at the Bureau of Standards by representatives of that institution together with one delegate each from the Physikalische-Technische Reichsanstalt, The National Physical Laboratory and the Laboratoire Central d'Electricité. Voltameters from all four institutions were put in series under a variety of experimental conditions. Standard Weston cells and resistance standards of the four laboratories were also intercompared. From the joint comparison of standard cells and silver voltameters particular values were assigned to the standard cells from each laboratory. The different countries thus have a common basis of measurement maintained by the aid of standard cells and resistance standards derived from the international voltameter investigation of 1910.

It was not found possible to draw up satisfactory and final specifications for the silver voltameter. Provisional specifications were submitted by the U. S. Bureau of Standards and more complete specifications have been proposed in correspondence between the national laboratories and members of the inter-

national committee since 1910, but no agreement upon final specifications has yet been reached.

Resistance Standards Used in Current Measurements. — Precise measurements of currents require a potentiometer, a standard cell and a resistance standard. The resistance must be so designed as to carry the maximum current without undue heating and consequent change of resistance. Accordingly the resistance metal must have a small temperature resistance coefficient and a sufficient area in contact with the air, oil, or other cooling fluid. It must have a small thermal electromotive force against copper. Manganin satisfies these conditions and is usually used. The terminals of the standard must have sufficient contact area so that there shall be no undue heating at contacts.[1] It must be so designed that the current distribution does not depend upon the mode of connection to the circuit.

Absolute Ampere. — The absolute ampere (10^{-1}c.g.s. electromagnetic units) differs by a negligible amount from the international ampere. Since the dimensional formula of the current in the electromagnetic system is $[L^{\frac{1}{2}}M^{\frac{1}{2}}/T\mu^{\frac{1}{2}}]$ which is equivalent to $[F^{\frac{1}{2}}/\mu^{\frac{1}{2}}]$, the absolute measurement of current involves fundamentally the measurement of a force in a medium of unit permeability. In most measurements of high precision an electrodynamometer has been used of the form known as a current balance.

The best value may be taken as (Birge, 1930)

$$1 \text{ international ampere} = 0.99995 \pm 0.00005 \text{ absolute ampere.}$$

The result may also be expressed in terms of the electrochemical equivalent of silver, and thus equals 0.00111805 g per absolute coulomb. The value is 0.00111800 g per international coulomb.

ELECTROMOTIVE FORCE

International Volt. — "The international volt is derived from the international ohm and ampere by Ohm's law. Its value is maintained by the aid of the Weston normal cell. The national standardizing laboratories have groups of such cells, to which values in terms of the international ohm and ampere have been assigned by international experiments, and thus form a basis of reference for the standardization of the standard cells used in practical measurements."

Weston Normal Cell. — The Weston normal cell is the standard used to maintain the international volt and, in conjunction with resistance standards, to maintain the international ampere. The cell is a simple voltaic combination

[1] See "Report to the International Committee on Electrical Units and Standards," 1912, p 199. For the Bureau of Standards investigations see Bull. Bureau of Standards, 9, pp. 209, 493; 10, p. 475, 1912-14; 13, p. 147, 1915; 9, p. 151, 1912; 13, pp. 447, 479, 1916.

having its anode or negative electrode of cadmium amalgam, consisting of 10 per cent by weight of cadmium and 90 per cent mercury. The cathode, or positive electrode, is pure mercury covered with a paste consisting of mercurous sulphate, cadmium-sulphate crystals, and solution. The electrolyte is cadmium-sulphate solution in contact with an excess of cadmium-sulphate crystals. The containing vessel is of glass, usually in the H form. Connection is made to the electrodes by platinum wires sealed into the glass. The cells are sealed, preferably hermetically, and in use are submerged in a constant-temperature oil bath. The resistance of a cell is about 600 to 1000 ohms. The Weston cell used with potentiometers is not the Weston normal cell, but differs from it only slightly, the cadmium-sulphate solution not being saturated. It is described in the next section below.

One of the great advantages of the Weston normal cell is its small change of electromotive force with change of temperature. At any temperature, t (centigrade), between 0° and 40°, $E_t = E_{20} - 0.0000406\ (t - 20) - 0.00000095\ (t - 20)^2 + 0.00000001\ (t - 20)^3$. This temperature formula was adopted by the London conference of 1908. That this formula may apply, the cell must be of a strictly uniform temperature throughout. One leg of the cell has a large positive and the other leg a large negative temperature coefficient. If the temperature of one leg changes faster than the other, the formula does not hold.

When the best of care is taken as to purity of materials and mode of procedure, Weston normal cells are reproducible within 1 part in 100,000. The source of the greatest variations has probably been in the mercurous sulphate. Cells using the best samples of this material have an electromotive force the constancy of which over a period of one year is about 1 part in 100,000. Only very meager specifications for the cell have as yet been agreed upon internationally, however, and the procedures in various laboratories differ in some respects.[1]

The basis of measurements of electromotive force is the same in all countries as the result of the joint international experiments of 1910. As already stated, a large number of observations were made at that time with the silver voltameter, and a considerable number of Weston normal cells from the national laboratories of England, France, Germany and the United States were compared. From the results of these voltameter experiments and from resistance measurements, the value

$$1.0183 \text{ international volts at } 20^\circ \text{ C}$$

was assigned to the Weston normal cell. A mean of the groups of cells from the four laboratories was taken as most accurately representing the Weston normal

[1] For the preliminary specifications which have been issued and the reports of the various investigations on the standard cells see the following references: Preliminary specifications, Wolff and Waters, Bull. B. of S. 3, p. 623, 1907; Clark and Weston Standard Cells, Wolff and Waters, ditto, 4, p. 1, 1907; Temperature formula of Weston Standard Cell, ditto, 5, p. 309, 1908; The materials, reproducibility, etc., of the Weston Cell, Helett, Phys. Rev. 22, p. 321, 1906; 23, p. 166, 1906; 27, pp. 33, 337, 1908; Mercurous sulphate, etc., Steinwehr, Zs. für Electroch. 12, p. 578, 1906; German value of cell, Jaeger and Steinwehr, ditto, 28, p. 367, 1908; National Physical Laboratory researches, Smith, Phil. Trans. 207, p. 393, 1908; On the Weston Cell, Haga and Boerema, Arch. Neerland, des Sci. Exactes, 3, p. 324, 1913.

cell. Each laboratory has means of preserving the unit. Any discrepancies between the bases of the different countries at the present time would be due only to possible variations in the reference cells of the national laboratories. Such discrepancies are probably less than 2 parts in 100,000.

The figure 1.0183 has been in use since January 1, 1911. The value used in the United States before 1911, 1.019126 at 20° C or 1.0189 at 25° C, was assigned to a certain group of cells maintained as the standard of electromotive force at the Bureau of Standards. The high value is partly due to the use of commercial mercurous sulphate in the cells. The old and the new values, 1.01926 and 1.0183, thus apply to different groups of cells. The group of cells to which the value 1.019126 was assigned before 1910 differed by 26 microvolts from the mean of the international group, such that the international group to which the value 1.0183 is now assigned had the value $1.019126 + 0.000026$, or 1.019152, in terms of the old United States basis. The difference between 1.019152 and 1.0183 is 0.000852.

The electromotive force of any Weston cell as now given is therefore 0.000852 volt smaller than on the old United States basis, i.e., the present international volt is 84 parts in 100,000 larger than the old international volt of the United States.

Upon the new international basis the Clark cell set up according to the old United States legal specifications has an e.m.f of 1.4328_0 international volts at 15° C. The Clark cell set up (with specially purified mercurous sulphate) according to improved specifications used at the Bureau of Standards has an e.m.f of 1.4325_0 international volts at 15° C or 1.4263_7 at 20° C.

Weston Portable Cell. — The standard cell used in practice is the Weston portable cell. It is like the Weston normal cell except that the cadmium-sulphate solution at ordinary temperatures is unsaturated. As usually made, the cadmium-sulphate solution is saturated at about 4° C; at higher temperatures the crystals are dissolved. Plugs of asbestos or other material hold the chemicals in place. Its resistance is usually about 200 to 311 ohms. The change of e.m.f. wholly negligible in most electrical measurements, is less than 0.00001 volt per degree C. The two legs of the cell have large and opposite temperature coefficients so that care must be taken that the temperature of the cell is kept uniform and the cell must be protected from draughts or large changes of temperature. The electromotive force of a portable cell ranges from 1.0181 to 1.0191 international volts and must be determined by comparison with standards. It decreases very slightly with time, usually less than 0.0001 volt per year.

Absolute and Semi-absolute Volt. — Since the direct determination of the volt in absolute measure presents great difficulties, it is derived by Ohm's law from the absolute measures of the ohm and ampere. From the absolute values of these,

$$1 \text{ international volt} = 1.00046 \pm 0.00005 \text{ absolute volts.}$$

The electromotive force of the Weston normal cell at 20° C is 1.0183_0 international volts and 1.0187_7 absolute volts. A semi-absolute volt is that potential

difference which exists between the terminals of a resistance of one *international* ohm when the latter carries a current of one *absolute* ampere. The e.m.f of the Weston normal cell may be taken as 1.01821 semi-absolute volts at 20° C.

QUANTITY OF ELECTRICITY

The international unit of quantity of electricity is the coulomb. The faraday is the quantity of electricity necessary to liberate 1 gram equivalent in electrolysis. It is equivalent to 96494 international coulombs = 96489 absolute coulombs (Birge).

Standards. — There are no standards of electric quantity. The silver voltameter may be used for its measurement since under ideal conditions the mass of metal deposited is proportional to the amount of electricity which has flowed.

CAPACITY

The unit generally used for capacity is the international microfarad or the one-millionth of the international farad. Capacities are commonly measured by comparison with standard capacities. The values of the standards are determined by measurement in terms of resistance and time. The standard is some form of condenser consisting of two sets of metal plates separated by a dielectric. The condenser should be surrounded by a metal shield connected to one set of plates rendering the capacity independent of the surroundings. An ideal condenser would have a constant capacity under all circumstances, with zero resistance in its leads and plates, and no absorption in the dielectric. Actual condensers vary with the temperature, atmospheric pressure, and the voltage, frequency, and time of charge and discharge. A well-constructed air condenser with heavy metal plates and suitable insulating supports is practically free from these effects and is used as a standard of capacity.

Practically air condenser plates must be separated by 1 mm or more and so cannot be of great capacity. The more the capacity is increased by approaching the plates, the less the mechanical stability and the less constant the capacity. Condensers of great capacity use solid dielectrics, preferably mica sheets with conducting plates of tinfoil. At constant temperature the best mica condensers are excellent standards. The dielectric absorption is small but not quite zero, so that the capacity of these standards with different methods of measurement must be carefully determined.

INDUCTANCE

The henry, the unit of self-inductance, is also the unit of mutual inductance. The henry has been known as the "quadrant" and the "secohm." The length of a quadrant or quarter of the earth's circumference is approximately 10^9 cms. and a henry is 10^9 cms. of inductance. Secohm is a contraction of second and ohm; the dimensions of inductance are $[TR]$ and this unit is based on the second and ohm.

Inductance Standards. — Inductance standards are measured in international units in terms of resistance and time or resistance and capacity by alternate-

current bridge methods. Inductances calculated from dimensions are in absolute electromagnetic units. The ratio of the international to the absolute henry is the same as the ratio of the corresponding ohms.

Since inductance is measured in terms of capacity and resistance by the bridge method about as simply and as conveniently as by comparison with standard inductances, it is not necessary to maintain standard inductances. They are however of value in magnetic, alternating-current, and absolute electrical measurements. A standard inductance is a circuit so wound that when used in a circuit it adds a definite amount of inductance. It must have either such a form or so great an inductance that the mutual inductance of the rest of the circuit upon it may be negligible. It usually is a wire coil wound all in the same direction to make self-induction a maximum. A standard, the inductance of which may be calculated from its dimensions, should be a single layer coil of very simple geometrical form. Standards of very small inductance, calculable from their dimensions, are of some simple device, such as a pair of parallel wires or a single turn of wire. With such standards great care must be used that the mutual inductance upon them of the leads and other parts of the circuit is negligible. Any inductance standard should be separated by long leads from the measuring bridge or other apparatus. It must be wound so that the distributed capacity between its turns is negligible; otherwise the apparent inductance will vary with the frequency.

POWER AND ENERGY

Power and energy, although mechanical and not primarily electrical quantities, are measurable with greater precision by electrical methods than in any other way. The watt and the electric units were so chosen in terms of the c.g.s. units that the product of the current in amperes by the electromotive force in volts gives the power in watts (for continuous or instantaneous values). The international watt, defined as "the energy expended per second by an unvarying electric current of one international ampere under an electric pressure of one international volt," differs but little from the absolute watt.

Standards and Measurements. — No standard is maintained for power or energy. Measurements are always made in electrical practice in terms of some of the purely electrical quantities represented by standards.

MAGNETIC UNITS

C.g.s. units are generally used for magnetic quantities. American practice is fairly uniform in names for these units: the c.g.s. unit of magnetomotive force is called the "gilbert," of reluctance, the "oersted," following the provisional definitions of the American Institute of Electrical Engineers (1894). The c.g.s. unit of flux is called the "maxwell" as defined by the 1900 Paris conference. The name "gauss" is used unfortunately both for the unit of induction (A.I.E.E. 1894) and for the unit of magnetic field intensity or magnetizing force. "This double usage, recently sanctioned by engineering societies, is based upon the mathematical convenience of defining both induction and magnetizing force

as the force on a unit magnetic pole in a narrow cavity in the material, the cavity being in one case perpendicular, in the other parallel, to the direction of the magnetization: this definition however applies only in the ordinary electromagnetic units. There are a number of reasons for considering induction and magnetizing force as two physically distinct quantities, just as electromotive force and current are physically different."

In the United States "gauss" has been used much more for the c.g.s. unit of induction than for the unit of magnetizing force. The longer name of "maxwell per cm²" is also sometimes used for this unit when it is desired to distinguish clearly between the two quantities. The c.g.s. unit of magnetizing force is usually called the "gilbert per cm."

A unit frequently used is the ampere-turn. It is convenient unit since it eliminates 4π in certain calculations. It is derived from the "ampere turn per cm." The following table shows the relations between a system built on the ampere-turn and the ordinary magnetic units.[1]

TABLE II.

THE ORDINARY AND THE AMPERE-TURN MAGNETIC UNITS.

Quantity		Ordinary magnetic units.	Ampere-turn units.	Ordinary units in 1 ampere-turn unit
Magnetomotive force	$\mathcal{F}$	Gilbert	Ampere-turn	$4\pi/10$
Magnetizing force	H	Gilbert per cm	Ampere-turn per cm	$4\pi/10$
Magnetic flux	Φ	Maxwell	Maxwell	1
Magnetic induction	B	Maxwell per cm ^{2} Gauss	Maxwell per cm ^{2} Gauss	1
Permeability	μ			1
Reluctance	R	Oersted	Ampere-turn per Maxwell	$4\pi/10$
Magnetization intensity	J		Maxwell per cm ^{2}	$1/4\pi$
Magnetic susceptibility	κ			$1/4\pi$
Magnetic pole strength	m		Maxwell	$1/4\pi$

[1] Dellinger, International System of Electric and Magnetic Units, Bull. Bureau of Standards, 13, p. 599, 1916.

PHYSICAL TABLES

SPELLING AND ABBREVIATIONS OF THE COMMON UNITS OF WEIGHT AND MEASURE

The spelling of the metric units is that adopted by the International Committee on Weights and Measures and given in the law legalizing the metric system in the United States (1866). The period is omitted after the metric abbreviations but not after those of the customary system. The exponents "2" and "3" are used to signify area and volume respectively in the metric units. The use of the same abbreviation for singular and plural is recommended. It is also suggested that only small letters be used for abbreviations except in the case of A. for acre, where the use of the capital letter is general. The following list is taken from circular 47 of the U. S. Bureau of Standards.

Unit.	Abbreviation.	Unit.	Abbreviation.
acre	A	kilogram	kg
are	a	kiloliter	kl
avoirdupois	av.	kilometer	km
barrel	bbl.	link	li.
board foot	bd. ft.	liquid	liq.
bushel	bu.	liter	l
carat, metric	c	meter	m
centare	ca	metric ton	t
centigram	cg	micron	μ
centiliter	cl	mile	mi.
centimeter	cm	milligram	mg
chain	ch.	milliliter	ml
cubic centimeter	cm^3	millimeter	mm
cubic decimeter	dm^3	millimicron	$m\mu$
cubic dekameter	dkm^3	minim	min. *or* ♏
cubic foot	cu. ft.	ounce	oz.
cubic hectometer	hm^3	ounce, apothecaries'	oz. ap. *or* ℥
cubic inch	cu. in.	ounce, avoirdupois	oz. av.
cubic kilometer	km^3	ounce, fluid	fl. oz.
cubic meter	m^3	ounce, troy	oz. t.
cubic mile	cu. mi.	peck	pk.
cubic millimeter	mm^3	pennyweight	dwt.
cubic yard	cu. yd.	pint	pt.
decigram	dg	pound	lb.
deciliter	dl	pound, apothecaries'	lb. ap.
decimeter	dm	pound, avoirdupois	lb. av.
decistere	ds	pound, troy	lb. t.
dekagram	dkg	quart	qt.
dekaliter	dkl	rod	rd.
dekameter	dkm	scruple, apothecaries'	s. ap. *or* ℈
dekastere	dks	square centimeter	cm^2
dram	dr.	square chain	sq. ch.
dram, apothecaries'	dr. ap. *or* ʒ	square decimeter	dm^2
dram, avoirdupois	dr. av.	square dekameter	dkm^2
dram, fluid	fl. dr.	square foot	sq. ft.
fathom	fath.	square hectometer	hm^2
foot	ft.	square inch	sq. in.
firkin	fir.	square kilometer	km^2
furlong	fur.	square meter	m^2
gallon	gal.	square mile	sq. mi.
grain	gr.	square millimeter	mm^2
gram	g	square rod	sq. rd.
hectare	ha	square yard	sq. yd.
hectogram	hg	stere	s
hectoliter	hl	ton	tn.
hectometer	hm	ton, metric	t
hogshead	hhd.	troy	t.
hundredweight	cwt.	yard	yd.
inch	in.		

TABLE 2

FUNDAMENTAL AND DERIVED UNITS

Conversion Factors

To change a quantity from one system of units to another: substitute in the corresponding conversion factor from the following table the ratios of the magnitudes of the *old* units to the *new* and multiply the old quantity by the resulting number. For example: to reduce velocity in miles per hour to feet per second, the conversion factor is lt^{-1}; $l = 5280/1$, $t = 3600/1$, and the factor is $5280/3600$ or 1.467. Or we may proceed as follows: e. g., to find the equivalent of 1 c.g.s. unit of angular momentum in the pd.ft.m unit, from the Table 1 g cm²/sec. $= x$ lb. ft.²/min. where x is the factor sought. Solving, $x = 1\text{g/lb.} \times \text{cm}^2/\text{ft.}^2 \times \text{min./sec.} = 1 \times .002205 \times .001076 \times 60 = .0001425$.

The dimensional formulæ lack one quality which is needed for completeness, an indication of their vector characteristics; such characteristics distinguish plane and solid angle, torque and energy, illumination and brightness.

(*a*) Fundamental Units

The fundamental units and conversion factors in the systems of units most commonly used are: Length [l]; Mass [m]; Time [t]; Temperature [θ]; and for the electrostatic system, Dielectric Constant [k]; for the electromagnetic system, Permeability [μ]. The formulae will also be given for the International System of electric and magnetic units based on the units length, resistance [r], current [i], and time.

(*b*) Derived Units

Name of unit. (Geometrical and dynamical.)	Conversion factor. [$m^x l^y t^z$]		
	x	y	z
Area, surface	0	2	0
Volume	0	3	0
Angle	0	0	0
Solid angle	0	0	0
Curvature	0	−1	0
Angular velocity	0	0	−1
Linear velocity	0	1	−1
Angular acceleration	0	0	−2
Linear acceleration	0	1	−2
Density	1	−3	0
Moment of inertia	1	2	0
Intensity of attraction	0	1	−2
Momentum	1	1	−1
Moment of momentum	1	2	−1
Angular momentum	1	2	−1
Force	1	1	−2
Moment of couple, torque	1	2	−2
Work, energy	1	2	−2
Power, activity	1	2	−3
Intensity of stress	1	−1	−2
Modulus of elasticity	1	−1	−2
Compressibility	−1	1	2
Resilience	1	−1	−2
Viscosity	1	−1	−1

Name of units. (Heat and light.)	Conversion factor. [$m^x l^y t^z \theta^r$]			
	x	y	z	r
Quantity of heat:				
thermal units	1	0	0	1
thermometric units	0	3	0	1
dynamical units	1	2	−2	0
Coefficient of thermal expansion	0	0	0	−1
Thermal conductivity:				
thermal units	1	−1	−1	0
thermometric units or diffusivity	0	2	−1	0
dynamical units	1	1	−3	−1
Thermal capacity	1	0	0	0
Latent heat:				
thermal units	0	0	0	1
dynamical units	0	2	−2	0
Joule's equivalent	0	2	−2	1
Entropy:				
heat in thermal units	1	0	0	0
heat in dynamical units	1	2	−2	1
Luminous intensity	0	0	0	1*
Illumination	0	−2	0	1*
Brightness	0	−2	0	1*
Visibility	−1	−2	3	1*
Luminous efficiency	−1	−2	3	1*

* For these formulæ the numbers in the last column are the exponents of F where F refers to the luminous flux

For definitions of these quantities see Table 348, page 333.

TABLE 2 (*continued*)

FUNDAMENTAL AND DERIVED UNITS

Conversion Factors

(*b*) DERIVED UNITS

NAME OF UNIT. (Electric and magnetic.)	Symbol.*	CONVERSION FACTOR.												
		Electrostatic system. $m^x l^y t^z k^v$				Electromagnetic system. $m^x l^y t^z \mu^v$				emu/esu †	International system. $r^x i^y l^z t^v$			
		x	y	z	v	x	y	z	v		x	y	z	v
Quantity of electricity	Q	$\frac{1}{2}$	$\frac{3}{2}$	-1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	c	0	1	0	1
Electric displacement	D	$\frac{1}{2}$	$-\frac{1}{2}$	-1	$\frac{1}{2}$	$\frac{1}{2}$	$-\frac{3}{2}$	0	$-\frac{1}{2}$	c	0	1	-2	1
Electric surface density	D	$\frac{1}{2}$	$-\frac{1}{2}$	-1	$\frac{1}{2}$	$\frac{1}{2}$	$-\frac{3}{2}$	0	$-\frac{1}{2}$	c	0	1	-2	1
Electric field intensity	$\mathcal{E}$	$\frac{1}{2}$	$-\frac{1}{2}$	-1	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	-2	$\frac{1}{2}$	1/c	1	1	1	0
Electric potential	V	$\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	-2	$\frac{1}{2}$	1/c	1	1	0	0
Electromotive force	E	$\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	-2	$\frac{1}{2}$	1/c	1	1	0	0
Electrostatic capacity	C	0	1	0	1	0	-1	2	-1	c^2	-1	0	0	0
Dielectric constant	K	0	0	0	1	0	-2	2	-1	c^2	-1	0	-1	1
Specific inductive capacity	—	0	0	0	0	0	0	0	0		0	0	0	0
Current	I	$\frac{1}{2}$	$\frac{3}{2}$	-2	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$	c	0	1	0	0
Electric conductivity	γ	0	0	-1	1	0	-2	1	-1	c^2	-1	0	-1	0
Resistivity	ρ	0	0	1	-1	0	2	-1	1	$1/c^2$	1	0	1	0
Conductance	g	0	1	-1	1	0	-1	1	-1	c^2	-1	0	0	0
Resistance	R	0	-1	1	-1	0	1	-1	1	$1/c^2$	1	0	0	0
Magnetic pole strength	m	$\frac{1}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	-1	$\frac{1}{2}$	1/c	1	1	0	1
Quantity of magnetism	m	$\frac{1}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	-1	$\frac{1}{2}$	1/c	1	1	0	1
Magnetic flux	Φ	$\frac{1}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	-1	$\frac{1}{2}$	1/c	1	1	0	1
Magnetic field intensity	H	$\frac{1}{2}$	$\frac{1}{2}$	-2	$\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	-1	$-\frac{1}{2}$	c	0	0	-1	0
Magnetizing force	H	$\frac{1}{2}$	$\frac{1}{2}$	-2	$\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	-1	$-\frac{1}{2}$	c	0	0	-1	0
Magnetic potential	Ω	$\frac{1}{2}$	$\frac{3}{2}$	-2	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$	c	0	1	0	0
Magnetomotive force	$\mathcal{F}$	$\frac{1}{2}$	$\frac{3}{2}$	-2	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$	c	0	1	0	0
Magnetic moment	—	$\frac{1}{2}$	$\frac{3}{2}$	0	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{2}$	-1	$\frac{1}{2}$	1/c	1	1	1	1
Intensity magnetization	J	$\frac{1}{2}$	$-\frac{3}{2}$	0	$-\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	-1	$\frac{1}{2}$	1/c	1	1	-2	1
Magnetic induction	B	$\frac{1}{2}$	$-\frac{3}{2}$	0	$-\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	-1	$\frac{1}{2}$	1/c	1	1	-2	1
Magnetic susceptibility	κ	0	-2	2	-1	0	0	0	1	$1/c^2$	1	0	-1	1
Magnetic permeability	μ	0	-2	2	-1	0	0	0	1	$1/c^2$	1	0	-1	1
Current density	—	$\frac{1}{2}$	$-\frac{1}{2}$	-2	$\frac{1}{2}$	$\frac{1}{2}$	$-\frac{3}{2}$	-1	$-\frac{1}{2}$	c	0	1	-2	0
Self-inductance	$\mathfrak{L}$	0	-1	2	-1	0	1	0	1	$1/c^2$	1	0	0	1
Mutual inductance	$\mathfrak{M}$	0	-1	2	-1	0	1	0	1	$1/c^2$	1	0	0	1
Magnetic reluctance	$\mathfrak{R}$	0	1	-2	1	0	-1	0	-1	c^2	-1	0	0	-1
Thermoelectric power‡	—	$\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$‡	$\frac{1}{2}$	$\frac{3}{2}$	-2	$\frac{1}{2}$‡	1/c	1	1	0	0‡
Peltier coefficient‡	—	$\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$‡	$\frac{1}{2}$	$\frac{3}{2}$	-2	$\frac{1}{2}$‡	1/c	1	1	0	0‡

* As adopted by American Institute of Electrical Engineers, 1915.
† c is the velocity of an electromagnetic wave in the ether $= 3 \times 10^{10}$ approximately.
‡ This conversion factor should include $[\theta^{-1}]$.

TABLE 3

TABLES FOR CONVERTING U. S. WEIGHTS AND MEASURES*

(1) CUSTOMARY TO METRIC

LINEAR.

	Inches to millimeters.	Feet to meters.	Yards to meters.	Miles to kilometers.
1	25.4001	0.304801	0.914402	1.60935
2	50.8001	0.609601	1.828804	3.21869
3	76.2002	0.914402	2.743205	4.82804
4	101.6002	1.219202	3.657607	6.43739
5	127.0003	1.524003	4.572009	8.04674
6	152.4003	1.828804	5.486411	9.65608
7	177.8004	2.133604	6.400813	11.26543
8	203.2004	2.438405	7.315215	12.87478
9	228.6005	2.743205	8.229616	14.48412

CAPACITY.

	Fluid drams to milliliters or cubic centimeters.	Fluid ounces to milliliters.	Liquid quarts to liters.	Gallons to liters.
1	3.70	29.57	0.94633	3.78533
2	7.39	59.15	1.89267	7.57066
3	11.09	88.72	2.83900	11.35600
4	14.79	118.29	3.78533	15.14133
5	18.48	147.87	4.73167	18.92666
6	22.18	177.44	5.67800	22.71199
7	25.88	207.01	6.62433	26.49733
8	29.57	236.58	7.57066	30.28266
9	33.27	266.16	8.51700	34.06799

SQUARE.

	Square inches to square centimeters.	Square feet to square decimeters.	Square yards to square meters.	Acres to hectares.
1	6.452	9.290	0.836	0.4047
2	12.903	18.581	1.672	0.8094
3	19.355	27.871	2.508	1.2141
4	25.807	37.161	3.345	1.6187
5	32.258	46.452	4.181	2.0234
6	38.710	55.742	5.017	2.4281
7	45.161	65.032	5.853	2.8328
8	51.613	74.323	6.689	3.2375
9	58.065	83.613	7.525	3.6422

WEIGHT.

	Grains to milligrams.	Avoirdupois ounces to grams.	Avoirdupois pounds to kilograms.	Troy ounces to grams.
1	64.7989	28.3495	0.45359	31.10348
2	129.5978	56.6991	0.90718	62.20696
3	194.3968	85.0486	1.36078	93.31044
4	259.1957	113.3981	1.81437	124.41392
5	323.9946	141.7476	2.26796	155.51740
6	388.7935	170.0972	2.72155	186.62088
7	453.5924	198.4467	3.17515	217.72437
8	518.3913	226.7962	3.62874	248.82785
9	583.1903	255.1457	4.08233	279.93133

CUBIC.

	Cubic inches to cubic centimeters.	Cubic feet to cubic meters.	Cubic yards to cubic meters.	Bushels to hectoliters.
1	16.387	0.02832	0.765	0.35239
2	32.774	0.05663	1.529	0.70479
3	49.161	0.08495	2.294	1.05718
4	65.549	0.11327	3.058	1.40957
5	81.936	0.14159	3.823	1.76196
6	98.323	0.16990	4.587	2.11436
7	114.710	0.19822	5.352	2.46675
8	131.097	0.22654	6.116	2.81914
9	147.484	0.25485	6.881	3.17154

1 Gunter's chain	=	20.1168	meters.
1 sq. statute mile	=	259.000	hectares.
1 fathom	=	1.829	meters.
1 nautical mile	=	1853.25	meters.
1 foot	=	0.304801	meter.
1 avoir. pound	=	453.5924277	grams.
15432.35639 grains	=	1.000	kilogram.

According to an executive order dated April 15, 1893, the United States yard is defined as 3600/3937 meter, and the avoirdupois pound as 1/2.20462 kilogram.

1 meter (international prototype) = 1553164.13 times the wave length of the red Cd. line. Benoit, Fabry and Perot. C. R. 144, 1907 differs only in the decimal portion from the measure of Michelson and Benoit 14 years earlier.

The length of the nautical mile given above and adopted by the U. S. Coast and Geodetic Survey many years ago, is defined as that of a minute of arc of a great circle of a sphere whose surface equals that of the earth (Clarke's Spheroid of 1866).

* Quoted from sheets issued by the United States Bureau of Standards.

TABLES FOR CONVERTING U. S. WEIGHTS AND MEASURES

(2) METRIC TO CUSTOMARY

LINEAR.

	Meters to inches.	Meters to feet.	Meters to yards.	Kilometers to miles.
1	39.3700	3.28083	1.093611	0.62137
2	78.7400	6.56167	2.187222	1.24274
3	118.1100	9.84250	3.280833	1.86411
4	157.4800	13.12333	4.374444	2.48548
5	196.8500	16.40417	5.468056	3.10685
6	236.2200	19.68500	6.561667	3.72822
7	275.5900	22.96583	7.655278	4.34959
8	314.9600	26.24667	8.748889	4.97096
9	354.3300	29.52750	9.842500	5.59233

CAPACITY.

	Milliliters or cubic centimeters to fluid drams.	Centiliters to fluid ounces.	Liters to quarts.	Decaliters to gallons.	Hectoliters to bushels.
1	0.27	0.338	1.0567	2.6418	2.8378
2	0.54	0.676	2.1134	5.2836	5.6756
3	0.81	1.014	3.1701	7.9253	8.5135
4	1.08	1.353	4.2268	10.5671	11.3513
5	1.35	1.691	5.2836	13.2089	14.1891
6	1.62	2.029	6.3403	15.8507	17.0269
7	1.89	2.367	7.3970	18.4924	19.8647
8	2.16	2.705	8.4537	21.1342	22.7026
9	2.43	3.043	9.5104	23.7760	25.5404

SQUARE.

	Square centimeters to square inches.	Square meters to square feet.	Square meters to square yards.	Hectares to acres.
1	0.1550	10.764	1.196	2.471
2	0.3100	21.528	2.392	4.942
3	0.4650	32.292	3.588	7.413
4	0.6200	43.055	4.784	9.884
5	0.7750	53.819	5.980	12.355
6	0.9300	64.583	7.176	14.826
7	1.0850	75.347	8.372	17.297
8	1.2400	86.111	9.568	19.768
9	1.3950	96.875	10.764	22.239

WEIGHT.

	Milligrams to grains.	Kilograms to grains.	Hectograms to ounces avoirdupois.	Kilograms to pounds avoirdupois.
1	0.01543	15432.36	3.5274	2.20462
2	0.03086	30864.71	7.0548	4.40924
3	0.04630	46297.07	10.5822	6.61387
4	0.06173	61729.43	14.1096	8.81849
5	0.07716	77161.78	17.6370	11.02311
6	0.09259	92594.14	21.1644	13.22773
7	0.10803	108026.49	24.6918	15.43236
8	0.12346	123458.85	28.2192	17.63698
9	0.13889	138891.21	31.7466	19.84160

CUBIC.

	Cubic centimeters to cubic inches.	Cubic decimeters to cubic inches.	Cubic meters to cubic feet.	Cubic meters to cubic yards.
1	0.0610	61.023	35.314	1.308
2	0.1220	122.047	70.269	2.616
3	0.1831	183.070	105.943	3.924
4	0.2441	244.094	141.258	5.232
5	0.3051	305.117	176.572	6.540
6	0.3661	366.140	211.887	7.848
7	0.4272	427.164	247.201	9.156
8	0.4882	488.187	282.516	10.464
9	0.5492	549.210	317.830	11.771

WEIGHT.

	Quintals to pounds av.	Milliers or tonnes to pounds av.	Kilograms to ounces Troy.
1	220.46	2204.6	32.1507
2	440.92	4409.2	64.3015
3	661.39	6613.9	96.4522
4	881.85	8818.5	128.6030
5	1102.31	11023.1	160.7537
6	1322.77	13227.7	192.9045
7	1543.24	15432.4	225.0552
8	1763.70	17637.0	257.2059
9	1984.16	19841.6	289.3567

By the concurrent action of the principal governments of the world an International Bureau of Weights and Measures has been established near Paris. Under the direction of the International Committee, two ingots were cast of pure platinum-iridium in the proportion of 9 parts of the former to 1 of the latter metal. From one of these a certain number of kilograms were prepared, from the other a definite number of meter bars. These standards of weight and length were intercompared, without preference, and certain ones were selected as International prototype standards. The others were distributed by lot, in September, 1889, to the different governments, and are called National prototype standards. Those apportioned to the United States were received in 1890, and are kept at the Bureau of Standards in Washington, D. C.

The metric system was legalized in the United States in 1866.

The International Standard Meter is derived from the Mètre des Archives, and its length is defined by the distance between two lines at 0° Centigrade, on a platinum-iridium bar deposited at the International Bureau of Weights and Measures.

The International Standard Kilogram is a mass of platinum-iridium deposited at the same place, and its weight in vacuo is the same as that of the Kilogram des Archives.

The liter is equal to the quantity of pure water at 4° C (760 mm Hg pressure) which weighs 1 kilogram and = 1.000027 cu. dm. (Trav. et Mem. Bureau Intern. des P. et M. 14, 1910, Benoit.)

MISCELLANEOUS EQUIVALENTS OF U. S. AND METRIC WEIGHTS AND MEASURES *

(For other equivalents than those below, see Table 3.)

LINEAR MEASURES.

1 mil (.001 in.) = 25.4001 μ
1 in. = .000015783 mile
1 hand (4 in.) = 10.16002 cm
1 link (.66 ft.) = 20.11684 cm
1 span (9 in.) = 22.86005 cm
1 fathom (6 ft.) = 1.828804 m
1 rod (25 links) = 5.029210 m
1 chain (4 rods) = 20.11684 m
1 light year (9.5×10^{12} km) = 5.9×10^{12} miles
1 parsec (31×10^{12} km) = 19×10^{12} miles
$\frac{1}{64}$ in. = .397 mm $\frac{1}{32}$ in. = .794 mm
$\frac{1}{16}$ in. = 1.588 mm $\frac{1}{8}$ in. = 3.175 mm
$\frac{1}{4}$ in. = 6.350 mm $\frac{1}{2}$ in. = 12.700 mm
1 Ångstrom unit = .0000000001 m
1 micron (μ) = .000001 m = .00003937 in.
1 millimicron (mμ) = .000000001 m
1 m = 4.970960 links = 1.093611 yds.
  = .198838 rod = .0497096 chain

SQUARE MEASURES.

1 sq. link (62.7264 sq. in.) = 404.6873 cm^2
1 sq. rod (625 sq. links) = 25.29295 m^2
1 sq. chain (16 sq. rods) = 404.6873 m^2
1 acre (10 sq. chains) = 4046.873 m^2
1 sq. mile (640 acres) = 2.589998 km^2
1 km^2 = .3861006 sq. mile
1 m^2 = 24.7104 sq. links = 10.76387 sq. ft.
  = .039537 sq. rod = .00247104 sq. chain

CUBIC MEASURES.

1 board foot (144 cu. in) = 2359.8 cm^3
1 cord (128 cu. ft.) = 3.625 m^3

CAPACITY MEASURES.

1 minim (♏) = .0616102 ml
1 fl. dram (60♏) = 3.69661 ml
1 fl. oz. (8 fl. dr.) = 1.80469 cu. in.
  = 29.5729 ml
1 gill (4 fl. oz.) = 7.21875 cu. in. = 118.292 ml
1 liq. pt. (28.875 cu. in.) = .473167 l
1 liq. qt. (57.75 cu. in.) = .946333 l
1 gallon (4 qt., 231 cu. in.) = 3.785332 l
1 dry pt. (33.6003125 cu. in.) = .550599 l
1 dry qt. (67.200625 cu. in.) = 1.101198 l
1 pk. (8 dry qt., 537.605 cu. in.) = 8.80958 l
1 bu. (4 pk., 2150.42 cu. in.) = 35.2383 l
1 firkin (9 gallons) = 34.06799 l
1 liter = .264178 gal. = 1.05671 liq. qt.
  = 33.8147 fl. oz. = 270.518 fl. dr.
1 ml = 16.2311 minims.
1 dkl = 18.620 dry pt. = 9.08102 dry qt.
  = 1.13513 pk. = .28378 bu.

MASS MEASURES.

Avoirdupois weights.

1 grain = .064798918 g
1 dram av. (27.34375 gr.) = 1.771845 g
1 oz. av. (16 dr. av.) = 28.349527 g
1 lb. av. (16 oz. av. or 7000 gr.)
  = 14.583333 oz. ap. (℥) or oz. t.
  = 1.2152778 or 7000/5760 lb. ap. or t.
  = 453.5924277 g
1 kg = 2.204622341 lb. av.
1 g = 15.432356 gr. = .5643833 dr. av.
  = .03527396 oz. av.
1 short hundred weight (100 lb.)
  = 45.359243 kg
1 long hundred weight (112 lb.)
  = 50.802352 kg
1 short ton (2000 lb.)
  = 907.18486 kg
1 long ton (2240 lb.)
  = 1016.04704 kg
1 metric ton = 0.9842064 long ton
  = 1.1023112 short tons

Troy weights.

1 pennyweight (dwt., 24 gr.) = 1.555174 g;
  gr., oz., pd. are same as apothecary

Apothecaries' weights.

1 gr. = 64.798918 mg
1 scruple (℈, 20 gr.) = 1.2959784 g
1 dram (ʒ, 3 ℈) = 3.8879351 g
1 oz. (℥, 8 ʒ) = 31.103481 g
1 lb. (12 ℥, 5760 gr.) = 373.24177 g
1 g = 15.432356 gr. = 0.771618 ℈
  = 0.2572059 ʒ = .03215074 ℥
1 kg = 32.150742 ℥ = 2.6792285 lb.

1 metric carat = 200 mg = 3.0864712 gr.

U. S. $\frac{1}{2}$ dollar should weigh 12.5 g and the smaller silver coins in proportion.

* Taken from Circular 47 of the U. S. Bureau of Standards, 1915, which see for more complete tables.

TABLE 5

EQUIVALENTS OF METRIC AND BRITISH IMPERIAL WEIGHTS AND MEASURES*

(1) METRIC TO IMPERIAL (For U. S. Weights and Measures, see Table 3)

LINEAR MEASURE.

1 millimeter (mm) (.001 m)	= 0.03937 in.
1 centimeter (.01 m)	= 0.39370 "
1 decimeter (.1 m)	= 3.93701 "
1 METER (m)	= 39.370113 " 3.280843 ft. 1.09361425 yds.
1 dekameter (10 m)	= 10.93614 "
1 hectometer (100 m)	= 109.361425 "
1 kilometer (1,000 m)	= 0.62137 mile.
1 myriameter (10,000 m)	= 6.21372 miles.
1 micron	= 0.001 mm.

SQUARE MEASURE.

1 sq. centimeter	= 0.1550 sq. in.
1 sq. decimeter (100 sq. cm)	= 15.500 sq. in.
1 sq. meter or centiare (100 sq. dm)	= 10.7639 sq. ft. 1.1960 sq. yds.
1 ARE (100 sq. m)	= 119.60 sq. yds.
1 hectare (100 ares or 10,000 sq. m)	= 2.4711 acres.

CUBIC MEASURE.

1 cu. centimeter (cc) (1,000 cubic millimeters)	= 0.0610 cu. in.
1 cu. decimeter (cd) (1,000 cubic centimeters)	= 61.024 " "
1 CU. METER or stere (1,000 cd)	= 35.3148 cu. ft. 1.307954 cu. yds.

MEASURE OF CAPACITY.

1 milliliter (ml) (.001 liter)	= 0.0610 cu. in.
1 centiliter (.01 liter)	= 0.61024 " " 0.070 gill.
1 deciliter (.1 liter)	= 0.176 pint.
1 LITER (1,000 cu. centimeters or 1 cu. decimeter)	= 1.75980 pints.
1 dekaliter (10 liters)	= 2.200 gallons.
1 hectoliter (100 ")	= 2.75 bushels.
1 kiloliter (1,000 ")	= 3.437 quarters.

APOTHECARIES' MEASURE.

1 cubic centimeter (1 gram w't)	= 0.03520 fluid ounce. 0.28157 fluid drachm. 15.43236 grains weight.
1 cu. millimeter	= 0.01693 minim.

AVOIRDUPOIS WEIGHT.

1 milligram (mg)	= 0.01543 grain.
1 centigram (.01 gram)	= 0.15432 "
1 decigram (.1 ")	= 1.54324 grains.
1 GRAM	= 15.43236 "
1 dekagram (10 grams)	= 5.64383 drams.
1 hectogram (100 ")	= 3.52739 oz.
1 KILOGRAM (1,000 ")	= 2.2046223 lb. 15432.3564 grains.
1 myriagram (10 kg)	= 22.04622 lbs.
1 quintal (100 ")	= 1.96841 cwt.
1 millier or tonne (1,000 kg)	= 0.9842 ton.

TROY WEIGHT.

1 GRAM	= 0.03215 oz. Troy. 0.64301 pennyweight. 15.43236 grains.

APOTHECARIES' WEIGHT.

1 GRAM	= 0.25721 drachm. 0.77162 scruple. 15.43236 grains.

NOTE.—The METER is the length, at the temperature of 0° C, of the platinum-iridium bar deposited at the International Bureau of Weights and Measures at Sèvres, near Paris, France.

The present legal equivalent of the meter is 39.370113 inches, as above stated.

The KILOGRAM is the mass of a platinum-iridium weight deposited at the same place.

The LITER contains one kilogram weight of distilled water at its maximum density (4° C), the barometer being at 760 millimeters.

* In accordance with the schedule adopted under the Weights and Measures (metric system) Act, 1897.

EQUIVALENTS OF METRIC AND BRITISH IMPERIAL WEIGHTS AND MEASURES

(2) METRIC TO IMPERIAL, MULTIPLES (For U. S. Weights and Measures, see Table 3)

LINEAR MEASURE.

	Millimeters to inches	Meters to feet.	Meters to yards.	Kilometers to miles.
1	0.03937011	3.28084	1.09361	0.62137
2	0.07874023	6.56169	2.18723	1.24274
3	0.11811034	9.84253	3.28084	1.86412
4	0.15748045	13.12337	4.37446	2.48549
5	0.19685056	16.40421	5.46807	3.10686
6	0.23622068	19.68506	6.56169	3.72823
7	0.27559079	22.96590	7.65530	4.34960
8	0.31496090	26.24674	8.74891	4.97097
9	0.35433102	29.52758	9.84253	5.59235

MEASURE OF CAPACITY.

	Liters to pints	Dekaliters to gallons	Hectoliters to bushels	Kiloliters to quarters.
1	1.75980	2.19975	2.74969	3.43712
2	3.51961	4.39951	5.49938	6.87423
3	5.27941	6.59926	8.24908	10.31135
4	7.03921	8.79902	10.99877	13.74846
5	8.79902	10.99877	13.74846	17.18558
6	10.55882	13.19852	16.49815	20.62269
7	12.31862	15.39828	19.24785	24.05981
8	14.07842	17.59803	21.99754	27.49692
9	15.83823	19.79778	24.74723	30.93404

SQUARE MEASURE.

	Square centimeters to square inches.	Square meters to square feet.	Square meters to square yards.	Hectares to acres.
1	0.15500	10.76393	1.19599	2.4711
2	0.31000	21.52786	2.39198	4.9421
3	0.46500	32.29179	3.58798	7.4132
4	0.62000	43.05572	4.78397	9.8842
5	0.77500	53.81965	5.97996	12.3553
6	0.93000	64.58357	7.17595	14.8263
7	1.08500	75.34750	8.37194	17.2974
8	1.24000	86.11143	9.56794	19.7685
9	1.39501	96.87536	10.76393	22.2395

WEIGHT (AVOIRDUPOIS).

	Milligrams to grains.	Kilograms to grains.	Kilograms to pounds.	Quintals to hundredweights.
1	0.01543	15432.356	2.20462	1.96841
2	0.03086	30864.713	4.40924	3.93683
3	0.04630	46297.069	6.61387	5.90524
4	0.06173	61729.426	8.81849	7.87365
5	0.07716	77161.782	11.02311	9.84206
6	0.09259	92594.138	13.22773	11.81048
7	0.10803	108026.495	15.43236	13.77889
8	0.12346	123458.851	17.63698	15.74730
9	0.13889	138891.208	19.84160	17.71572

CUBIC MEASURE. / APOTHECARIES' MEASURE.

	Cubic decimeters to cubic inches. (Cubic Measure)	Cubic meters to cubic feet. (Cubic Measure)	Cubic meters to cubic yards. (Cubic Measure)	Cub. centimeters to fluid drachms. (Apothecaries' Measure)
1	61.02390	35.31476	1.30795	0.28157
2	122.04781	70.62952	2.61591	0.56314
3	183.07171	105.94428	3.92386	0.84471
4	244.09561	141.25904	5.23182	1.12627
5	305.11952	176.57379	6.53977	1.40784
6	366.14342	211.88855	7.84772	1.68941
7	427.16732	247.20331	9.15568	1.97098
8	488.19123	282.51807	10.46363	2.25255
9	549.21513	317.83283	11.77159	2.53412

AVOIRDUPOIS (*cont.*) / TROY WEIGHT. / APOTHECARIES' WEIGHT.

	Milliers or tonnes to tons. (Avoirdupois, cont.)	Grams to ounces Troy. (Troy Weight)	Grams to pennyweights. (Troy Weight)	Grams to scruples. (Apothecaries' Weight)
1	0.98421	0.03215	0.64301	0.77162
2	1.96841	0.06430	1.28603	1.54324
3	2.95262	0.09645	1.92904	2.31485
4	3.93683	0.12860	2.57206	3.08647
5	4.92103	0.16075	3.21507	3.85809
6	5.90524	0.19290	3.85809	4.62971
7	6.88944	0.22506	4.50110	5.40132
8	7.87365	0.25721	5.14412	6.17294
9	8.85786	0.28936	5.78713	6.94456

EQUIVALENTS OF BRITISH IMPERIAL AND METRIC WEIGHTS AND MEASURES

(3) IMPERIAL TO METRIC (For U. S. Weights and Measures, see Table 3)

LINEAR MEASURE.

1 inch . . . . . . =	25.400 millimeters.
1 foot (12 in.) . . =	0.30480 meter.
1 YARD (3 ft.) . . =	0.914399 "
1 pole ($5\frac{1}{2}$ yd.) . . =	5.0292 meters.
1 chain (22 yd. or 100 links) =	20.1168 "
1 furlong (220 yd.) =	201.168 "
1 mile (1,760 yd.) . =	1.6093 kilometers.
1 yard . . . . . =	1420210. × $Cd_r\lambda$. (Tutton 1932)

SQUARE MEASURE.

1 square inch . . =	6.4516 sq. centimeters.
1 sq. ft. (144 sq. in.) =	9.2903 sq. decimeters.
1 SQ. YARD (9 sq. ft.) =	0.836126 sq. meters.
1 perch ($30\frac{1}{4}$ sq. yd.) =	25.293 sq. meters.
1 rood (40 perches) =	10.117 ares.
1 ACRE (4840 sq. yd.) =	0.40468 hectare.
1 sq. mile (640 acres) =	259.00 hectares.

CUBIC MEASURE.

1 cu. inch =	16.387 cu. centimeters.
1 cu. foot (1728 cu. in.) =	0.028317 cu. meter, or 28.317 cu. decimeters.
1 CU. YARD (27 cu. ft.) =	0.76455 cu. meter.

APOTHECARIES' MEASURE.

1 gallon (8 pints or 160 fluid ounces) =	4.5459631 liters.
1 fluid ounce, f ℥ (8 drachms) =	28.4123 cubic centimeters.
1 fluid drachm, f ʒ (60 minims) =	3.5515 cubic centimeters.
1 minim, ♏ (0.91146 grain weight) =	0.05919 cubic centimeters.

NOTE.—The Apothecaries' gallon is of the same capacity as the Imperial gallon.

MEASURE OF CAPACITY.

1 gill . . . . =	1.42 deciliters.
1 pint (4 gills) . . . =	0.568 liter.
1 quart (2 pints) . . =	1.136 liters.
1 GALLON (4 quarts) =	4.5459631 "
1 peck (2 gal.) . . =	9.092 "
1 bushel (8 gal.) . =	3.637 dekaliters.
1 quarter (8 bushels) =	2.909 hectoliters.

AVOIRDUPOIS WEIGHT.

1 grain . . . . . . =	64.8 milligrams.
1 dram . . . . . =	1.772 grams.
1 ounce (16 dr.) . . =	28.350 "
1 POUND (16 oz. or 7,000 grains) =	0.45359243 kg.
1 stone (14 lb.) . . =	6.350 "
1 quarter (28 lb.) . =	12.70 "
1 hundredweight (112 lb.) =	50.80 " 0.5080 quintal.
1 ton (20 cwt.) . =	1.0160 tonnes or 1016 kilograms.

TROY WEIGHT.

1 Troy OUNCE (480 grains av.)	= 31.1035 grams.
1 pennyweight (24 grains)	= 1.5552 "

NOTE.—The Troy grain is of the same weight as the Avoirdupois grain.

APOTHECARIES' WEIGHT.

1 ounce (8 drachms)	= 31.1035 grams.
1 drachm, ʒi (3 scruples)	= 3.888 "
1 scruple, ℈i (20 grains)	= 1.296 "

NOTE.—The Apothecaries' ounce is of the same weight as the Troy ounce. The Apothecaries' grain is also of the same weight as the Avoirdupois grain.

NOTE.—The YARD is the length at 62° F., marked on a bronze bar deposited with the Board of Trade.
The POUND is the weight of a piece of platinum weighed in vacuo at the temperature of 0° C., and which is also deposited with the Board of Trade.
The GALLON contains 10 lb. weight of distilled water at the temperature of 62° F., the barometer being at 30 inches.

EQUIVALENTS OF BRITISH IMPERIAL AND METRIC WEIGHTS AND MEASURES

(4) IMPERIAL TO METRIC, MULTIPLES

(For U. S. Weights and Measures, see Table 3)

LINEAR MEASURE.

	Inches to centimeters.	Feet to meters.	Yards to meters.	Miles to kilometers.
1	2.539998	0.30480	0.91440	1.60934
2	5.079996	0.60960	1.82880	3.21869
3	7.619993	0.91440	2.74320	4.82803
4	10.159991	1.21920	3.65760	6.43737
5	12.699989	1.52400	4.57200	8.04671
6	15.239987	1.82880	5.48640	9.65606
7	17.779984	2.13360	6.40080	11.26540
8	20.319982	2.43840	7.31519	12.87474
9	22.859980	2.74320	8.22959	14.48408

MEASURE OF CAPACITY.

	Quarts to liters.	Gallons to liters.	Bushels to dekaliters.	Quarters to hectoliters.
1	1.13649	4.54596	3.63677	2.90942
2	2.27298	9.09193	7.27354	5.81883
3	3.40947	13.63789	10.91031	8.72825
4	4.54596	18.18385	14.54708	11.63767
5	5.68245	22.72982	18.18385	14.54708
6	6.81894	27.27578	21.82062	17.45650
7	7.95544	31.82174	25.45739	20.36591
8	9.09193	36.36770	29.09416	23.27533
9	10.22842	40.91367	32.73093	26.18475

SQUARE MEASURE.

	Square inches to square centimeters.	Square feet to square decimeters.	Square yards to square meters.	Acres to hectares.
1	6.45159	9.29029	0.83613	0.40468
2	12.90318	18.58058	1.67225	0.80937
3	19.35477	27.87086	2.50838	1.21405
4	25.80636	37.16115	3.34450	1.61874
5	32.25794	46.45144	4.18063	2.02342
6	38.70953	55.74173	5.01676	2.42811
7	45.16112	65.03201	5.85288	2.83279
8	51.61271	74.32230	6.68901	3.23748
9	58.06430	83.61259	7.52513	3.64216

WEIGHT (AVOIRDUPOIS).

	Grains to milligrams.	Ounces to grams.	Pounds to kilograms.	Hundredweights to quintals.
1	64.79892	28.34953	0.45359	0.50802
2	129.59784	56.69905	0.90718	1.01605
3	194.39675	85.04858	1.36078	1.52407
4	259.19567	113.39811	1.81437	2.03209
5	323.99459	141.74763	2.26796	2.54012
6	388.79351	170.09716	2.72155	3.04814
7	453.59243	198.44669	3.17515	3.55616
8	518.39135	226.79621	3.62874	4.06419
9	583.19026	255.14574	4.08233	4.57221

CUBIC MEASURE. / APOTHECARIES' MEASURE.

	Cubic inches to cubic centimeters.	Cubic feet to cubic meters.	Cubic yards to cubic meters.	Apothecaries' Measure: Fluid drachms to cubic centimeters.
1	16.38702	0.02832	0.76455	3.55153
2	32.77404	0.05663	1.52911	7.10307
3	49.16106	0.08495	2.29366	10.65460
4	65.54808	0.11327	3.05821	14.20613
5	81.93511	0.14158	3.82276	17.75767
6	98.32213	0.16990	4.58732	21.30920
7	114.70915	0.19822	5.35187	24.86074
8	131.09617	0.22653	6.11642	28.41227
9	147.48319	0.25485	6.88098	31.96380

AVOIRDUPOIS (*cont.*). / TROY WEIGHT / APOTHECARIES' WEIGHT

	Avoirdupois (*cont.*): Tons to milliers or tonnes.	Troy Weight: Ounces to grams.	Troy Weight: Pennyweights to grams.	Apothecaries' Weight: Scruples to grams.
1	1.01605	31.10348	1.55517	1.29598
2	2.03209	62.20696	3.11035	2.59196
3	3.04814	93.31044	4.66552	3.88794
4	4.06419	124.41392	6.22070	5.18391
5	5.08024	155.51740	7.77587	6.47989
6	6.09628	186.62088	9.33104	7.77587
7	7.11233	217.72437	10.88622	9.07185
8	8.12838	248.82785	12.44139	10.36783
9	9.14442	279.93133	13.99657	11.66381

DERIVATIVES AND INTEGRALS *

$d\,ax$	$= a\,dx$
$d\,uv$	$= \left(u\frac{dv}{dx}+v\frac{du}{dx}\right)dx$
$d\,\frac{u}{v}$	$= \left(\frac{v\frac{du}{dx}-u\frac{dv}{dx}}{v^2}\right)dx$
$d\,x^n$	$= nx^{n-1}\,dx$
$d\,f(u)$	$= d\frac{f(u)}{du}\cdot\frac{du}{dx}\cdot dx$
$d\,e^x$	$= e^x\,dx$
$d\,e^{ax}$	$= a\,e^{ax}\,dx$
$d\,\log_e x$	$= \frac{1}{x}\,dx$
$d\,x^x$	$= x^x\,(1+\log_e x)\,dx$
$d\,\sin x$	$= \cos x\,dx$
$d\,\cos x$	$= -\sin x\,dx$
$d\,\tan x$	$= \sec^2 x\,dx$
$d\,\cot x$	$= -\csc^2 x\,dx$
$d\,\sec x$	$= \tan x\,\sec x\,dx$
$d\,\csc x$	$= -\cot x\,.\,\csc x\,dx$
$d\,\sin^{-1} x$	$= (1-x^2)^{-\frac{1}{2}}\,dx$
$d\,\cos^{-1} x$	$= -(1-x^2)^{-\frac{1}{2}}\,dx$
$d\,\tan^{-1} x$	$= (1+x^2)^{-1}\,dx$
$d\,\cot^{-1} x$	$= -(1+x^2)^{-1}\,dx$
$d\,\sec^{-1} x$	$= x^{-1}\,(x^2-1)^{-\frac{1}{2}}\,dx$
$d\,\csc^{-1} x$	$= -x^{-1}\,(x^2-1)^{-\frac{1}{2}}\,dx$
$d\,\sinh x$	$= \cosh x\,dx$
$d\,\cosh x$	$= \sinh x\,dx$
$d\,\tanh x$	$= \mathrm{sech}^2\,x\,dx$
$d\,\coth x$	$= -\mathrm{csch}^2\,x\,dx$
$d\,\mathrm{sech}\,x$	$= -\mathrm{sech}\,x\,\tanh dx$
$d\,\mathrm{csch}\,x$	$= -\mathrm{csch}\,x\,.\,\coth x\,dx$
$d\,\sinh^{-1} x$	$= (x^2+1)^{-\frac{1}{2}}\,dx$
$d\,\cosh^{-1} x$	$= (x^2-1)^{-\frac{1}{2}}\,dx$
$d\,\tanh^{-1} x$	$= (1-x^2)^{-1}\,dx$
$d\,\coth^{-1} x$	$= (1-x^2)^{-1}\,dx$
$d\,\mathrm{sech}^{-1}\,x$	$= -x^{-1}\,(1-x^2)^{-\frac{1}{2}}\,dx$
$d\,\mathrm{csch}^{-1}\,x$	$= -x^{-1}\,(x^2+1)^{-\frac{1}{2}}$

$\int x^n\,dx$	$=\frac{x^{n+1}}{n+1}$, unless $n=-1$
$\int\frac{dx}{x}$	$= \log x$
$\int e^x\,dx$	$= e^x$
$\int e^{ax}dx$	$=\frac{1}{a}\,e^{ax}$
$\int x^m e^{ax}\,dx$	$= \frac{x^m e^{ax}}{a}-\frac{m}{a}\int x^{m-1}e^{ax}\,dx$
$\int \log x\,dx$	$= x\log x - x$
$\int u\,dv$	$= u\,v-\int v\,du$
$\int (a+bx)^n\,dx$	$=\frac{(a+bx)^{n+1}}{(n+1)b}$
$\int (a^2+x^2)^{-1}\,dx$	$= \frac{1}{a}\tan^{-1}\frac{x}{a} = \frac{1}{a}\sin^{-1}\frac{x}{\sqrt{x^2+a^2}}$
$\int (a^2-x^2)^{-1}\,dx$	$= \frac{1}{2a}\log\frac{a+x}{a-x}$
$\int (a^2-x^2)^{-\frac{1}{2}}\,dx$	$= \sin^{-1}\frac{x}{a}$, or $-\cos^{-1}\frac{x}{a}$
$\int x(a^2\pm x^2)^{-\frac{1}{2}}\,dx$	$= \pm(a^2\pm x^2)^{\frac{1}{2}}$
$\int \sin^2 x\,dx$	$= -\frac{1}{2}\cos x\sin x+\frac{1}{2}x$
$\int \cos^2 x\,dx$	$= \frac{1}{2}\sin x\cos x+\frac{1}{2}x$
$\int \sin x\cos x\,dx$	$= \frac{1}{2}\sin^2 x$
$\int (\sin x\cos x)^{-1}\,dx$	$= \log\tan x$
$\int \tan x\,dx$	$= -\log\cos x$
$\int \tan^2 x\,dx$	$= \tan x - x$
$\int \cot x\,dx$	$= \log\sin x$
$\int \cot^2 x\,dx$	$= -\cot x - x$
$\int \csc x\,dx$	$= \log\tan\frac{1}{2}x$
$\int x\sin x\,dx$	$= \sin x - x\cos x$
$\int x\cos x\,dx$	$= \cos x + x\sin x$
$\int \tanh x\,dx$	$= \log\cosh x$
$\int \coth x\,dx$	$= \log\sinh x$
$\int \mathrm{sech}\,x\,dx$	$= 2\tan^{-1} e^x = \mathrm{gd}\,u$
$\int \mathrm{csch}\,x\,dx$	$= \log\tanh\frac{x}{2}$
$\int x\sinh x\,dx$	$= x\cosh x - \sinh x$
$\int x\cosh x\,dx$	$= x\sinh x - \cosh x$
$\int \sinh^2 x\,dx$	$= \frac{1}{2}(\sinh x\cosh x - x)$
$\int \cosh^2 x\,dx$	$= \frac{1}{2}(\sinh x\cosh x + x)$
$\int \sinh x\cosh x\,dx$	$=\frac{1}{4}\cosh(2x)$

* See also accompanying table of derivatives. For example: $\int \cos.\,x\,dx = \sin.\,x$ + constant.

SERIES

$$(x+y)^n = x^n + \frac{n}{1} x^{n-1} y + \frac{n(n-1)}{2!} x^{n-2} y^2 + \ldots$$

$$\frac{n(n-1)\ldots(n-m+1)}{m!} x^{n-m} y^m + \ldots \qquad (y^2 < x^2)$$

$$(1 \pm x)^n = 1 \pm nx + \frac{n(n-1)x^2}{2!} \pm \frac{n(n-1)(n-2)x^3}{3!} + \ldots + \frac{(\pm 1)^k n!\, x^k}{(n-k)!\, k!} + \ldots \quad (x^2 < 1)$$

$$(1 \pm x)^{-n} = 1 \mp nx + \frac{n(n+1)}{2!} x^2 \mp \frac{n(n+1)(n+2)x^3}{3!} + \ldots$$

$$(\mp 1)^k \frac{(n+k-1)\, x^k}{(n-1)!\, k!} + \ldots \quad (x^2 < 1)$$

$$(1 \pm x)^{-1} = 1 \mp x + x^2 \mp x^3 + x^4 \mp x^5 + \ldots \qquad (x^2 < 1)$$

$$(1 \pm x)^{-2} = 1 \mp 2x + 3x^2 \mp 4x^3 + 5x^4 \mp 6x^5 + \ldots \qquad (x^2 < 1)$$

$$f(x+h) = f(x) + h f'(x) + \frac{h^2}{2!} f''(x) + \ldots + \frac{h^n}{n!} f^{(n)}(x) + \ldots$$ Taylor's series.

$$f(x) = f(o) + \frac{x}{1} f'(o) + \frac{x^2}{2!} f''(o) + \ldots \frac{x^n}{n!} f^{(n)}(o) + \ldots$$ Maclaurin's series.

$$e = \lim\left(1 + \frac{1}{n}\right)^n = 1 + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \frac{1}{4!} + \ldots$$

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \ldots \qquad (x^2 < \infty)$$

$$a^x = 1 + x \log a + \frac{(x \log a)^2}{2!} + \frac{(x \log a)^3}{3!} + \ldots \qquad (x^2 < \infty)$$

$$\log x = \frac{x-1}{x} + \frac{1}{2}\left(\frac{x-1}{x}\right)^2 + \frac{1}{3}\left(\frac{x-1}{x}\right)^3 + \ldots \qquad (x > \tfrac{1}{2})$$

$$= (x-1) - \tfrac{1}{2}(x-1)^2 + \tfrac{1}{3}(x-1)^3 - \ldots \qquad (2 > x > 0)$$

$$= 2\left[\frac{x-1}{x+1} + \frac{1}{3}\left(\frac{x-1}{x+1}\right)^3 + \frac{1}{5}\left(\frac{x-1}{x+1}\right)^5 + \ldots\right] \qquad (x > 0)$$

$$\log(1+x) = x - \tfrac{1}{2}x^2 + \tfrac{1}{3}x^3 - \tfrac{1}{4}x^4 + \ldots \qquad (x^2 < 1)$$

$$\sin x = \frac{1}{2i}(e^{ix} - e^{-ix}) = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \ldots \qquad (x^2 < \infty)$$

$$\cos x = \frac{1}{2}(e^{ix} + e^{-ix}) = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \ldots = 1 - \operatorname{versin} x \qquad (x^2 < \infty)$$

$$\tan x = x + \frac{x^3}{3} + \frac{2x^5}{15} + \frac{17x^7}{315} + \frac{62}{2835} x^9 + \ldots \qquad \left(x^2 < \frac{\pi^2}{4}\right)$$

$$\sin^{-1} x = \frac{\pi}{2} - \cos.^{-1} x = x + \frac{x^3}{6} + \frac{1}{2} \cdot \frac{3}{4} \cdot \frac{x^5}{5} + \frac{1}{2} \cdot \frac{3}{4} \cdot \frac{5}{6} \cdot \frac{x^7}{7} + \ldots \qquad (x^2 < 1)$$

$$\tan^{-1} x = \frac{\pi}{2} - \cot.^{-1} x = x - \frac{1}{3}x^3 + \frac{1}{5}x^5 - \frac{1}{7}x^7 + \ldots \qquad (x^2 < 1)$$

$$= \frac{\pi}{2} - \frac{1}{x} + \frac{1}{3x^3} - \frac{1}{5x^5} + \ldots \qquad (x^2 > 1)$$

$$\sinh x = \frac{1}{2}(e^x - e^{-x}) = x + \frac{x^3}{3!} + \frac{x^5}{5!} + \frac{x^7}{7!} + \ldots \qquad (x^2 < \infty)$$

TABLE 7 (*continued*)—SERIES

$$\cosh x = \frac{1}{2}(e^x + e^{-x}) = 1 + \frac{x^2}{2!} + \frac{x^4}{4!} + \frac{x^6}{6!} + \ldots \qquad (x^2 < \infty)$$

$$\tanh x = x - \frac{1}{3}x^3 + \frac{2}{15}x^5 - \frac{17}{315}x^7 + \ldots \qquad (x^2 < \tfrac{1}{4}\pi^2)$$

$$\sinh^{-1} x = x - \frac{1}{2}\frac{x^3}{3} + \frac{1}{2}\cdot\frac{3}{4}\cdot\frac{x^5}{5} - \frac{1}{2}\cdot\frac{3}{4}\cdot\frac{5}{6}\frac{x^7}{7} + \ldots \qquad (x^2 < 1)$$

$$= \log 2x + \frac{1}{2}\frac{1}{2x^2} - \frac{1}{2}\frac{3}{4}\frac{1}{4x^4} + \frac{1}{2}\frac{3}{4}\frac{5}{6}\frac{1}{6x^6} - \ldots \qquad (x^2 > 1)$$

$$\cosh^{-1} x = \log 2x - \frac{1}{2}\frac{1}{2x^2} - \frac{1}{2}\frac{3}{4}\frac{1}{4x^4} - \frac{1}{2}\frac{3}{4}\frac{5}{6}\frac{1}{6x^6} - \ldots \qquad (x^2 > 1)$$

$$\tanh^{-1} x = x + \frac{1}{3}x^3 + \frac{1}{5}x^5 + \frac{1}{7}x^7 + \ldots \qquad (x^2 < 1)$$

$$\mathrm{gd}\, x = \phi = x - \frac{1}{6}x^3 + \frac{1}{24}x^5 - \frac{61}{5040}x^7 + \ldots \qquad (x \text{ small})$$

$$= \frac{\pi}{2} - \mathrm{sech}.\, x - \frac{1}{2}\frac{\mathrm{sech}^3 x}{3} - \frac{1}{2}\frac{3}{4}\frac{\mathrm{sech}^6 x}{5} - \ldots \qquad (x \text{ large})$$

$$x = \mathrm{gd}^{-1}\phi = \phi + \frac{1}{6}\phi^3 + \frac{1}{24}\phi^5 + \frac{61}{5040}\phi^7 + \ldots \qquad \left(\phi < \frac{\pi}{2}\right)$$

$$f(x) = \frac{1}{2}b_0 + b_1 \cos\frac{\pi x}{c} + b_2 \cos\frac{2\pi x}{c} + \ldots$$

$$+ a_1 \sin\frac{\pi x}{c} + a_2 \cos\frac{2\pi x}{c} + \ldots (-c < x < c)$$

$$a_m = \frac{1}{c}\int_{-c}^{+c} f(x)\sin\frac{m\pi x}{c}\,dx$$

$$b_m = \frac{1}{c}\int_{-c}^{+c} f(x)\cos\frac{m\pi x}{c}\,dx$$

TABLE 8.—MATHEMATICAL CONSTANTS

		Numbers.	Logarithms.
e = 2.71828 18285		π = 3.14159 26536	0.49714 98727
e^{-1} = 0.36787 94412		π^2 = 9.86960 44011	0.99429 97454
M = $\log_{10} e$ = 0.43429 44819		$\frac{1}{\pi}$ = 0.31830 98862	9.50285 01273
$(\mathrm{M})^{-1}$ = $\log_e 10$ = 2.30258 50930		$\sqrt{\pi}$ = 1.77245 38509	0.24857 49363
$\log_{10}\log_{10} e$ = 9.63778 43113		$\frac{\sqrt{\pi}}{2}$ = 0.88622 69255	9.94754 49407
$\log_{10} 2$ = 0.30102 99957		$\frac{1}{\sqrt{\pi}}$ = 0.56418 95835	9.75142 50637
$\log_e 2$ = 0.69314 71806		$\frac{2}{\sqrt{\pi}}$ = 1.12837 91671	0.05245 50593
$\log_{10} x$ = M.$\log_e x$		$\sqrt{\frac{\pi}{2}}$ = 1.25331 41373	0.09805 99385
$\log_B x$ = $\log_e x.\ \log_B e$		$\sqrt{\frac{2}{\pi}}$ = 0.79788 45608	9.90194 00615
= $\log_e x \div \log_e \mathrm{B}$		$\frac{\pi}{4}$ = 0.78539 81634	9.89508 98814
$\log_e \pi$ = 1.14472 98858		$\frac{\sqrt{\pi}}{4}$ = 0.44311 34627	9.64651 49450
ρ = 0.47693 62762		$\frac{4}{3}\pi$ = 4.18879 02048	0.62208 86093
$\log \rho$ = 9.67846 03565		$\frac{e}{\sqrt{2\pi}}$ = 1.08443 75514	0.03520 45477

TABLE 9

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
10	100.000	100	1000	3.1623	**65**	15.3846	4225	274625	8.0623
11	90.9091	121	1331	3.3166	66	15.1515	4356	287496	8.1240
12	83.3333	144	1728	3.4641	67	14.9254	4489	300763	8.1854
13	76.9231	169	2197	3.6056	68	14.7059	4624	314432	8.2462
14	71.4286	196	2744	3.7417	69	14.4928	4761	328509	8.3066
15	66.6667	225	3375	3.8730	**70**	14.2857	4900	343000	8.3666
16	62.5000	256	4096	4.0000	71	14.0845	5041	357911	8.4261
17	58.8235	289	4913	4.1231	72	13.8889	5184	373248	8.4853
18	55.5556	324	5832	4.2426	73	13.6986	5329	389017	8.5440
19	52.6316	361	6859	4.3589	74	13.5135	5476	405224	8.6023
20	50.0000	400	8000	4.4721	**75**	13.3333	5625	421875	8.6603
21	47.6190	441	9261	4.5826	76	13.1579	5776	438976	8.7178
22	45.4545	484	10648	4.6904	77	12.9870	5929	456533	8.7750
23	43.4783	529	12167	4.7958	78	12.8205	6084	474552	8.8318
24	41.6667	576	13824	4.8990	79	12.6582	6241	493039	8.8882
25	40.0000	625	15625	5.0000	**80**	12.5000	6400	512000	8.9443
26	38.4615	676	17576	5.0990	81	12.3457	6561	531441	9.0000
27	37.0370	729	19683	5.1962	82	12.1951	6724	551368	9.0554
28	35.7143	784	21952	5.2915	83	12.0482	6889	571787	9.1104
29	34.4828	841	24389	5.3852	84	11.9048	7056	592704	9.1652
30	33.3333	900	27000	5.4772	**85**	11.7647	7225	614125	9.2195
31	32.2581	961	29791	5.5678	86	11.6279	7396	636056	9.2736
32	31.2500	1024	32768	5.6569	87	11.4943	7569	658503	9.3274
33	30.3030	1089	35937	5.7446	88	11.3636	7744	681472	9.3808
34	29.4118	1156	39304	5.8310	89	11.2360	7921	704969	9.4340
35	28.5714	1225	42875	5.9161	**90**	11.1111	8100	729000	9.4868
36	27.7778	1296	46656	6.0000	91	10.9890	8281	753571	9.5394
37	27.0270	1369	50653	6.0828	92	10.8696	8464	778688	9.5917
38	26.3158	1444	54872	6.1644	93	10.7527	8649	804357	9.6437
39	25.6410	1521	59319	6.2450	94	10.6383	8836	830584	9.6954
40	25.0000	1600	64000	6.3246	**95**	10.5263	9025	857375	9.7468
41	24.3902	1681	68921	6.4031	96	10.4167	9216	884736	9.7980
42	23.8095	1764	74088	6.4807	97	10.3093	9409	912673	9.8489
43	23.2558	1849	79507	6.5574	98	10.2041	9604	941192	9.8995
44	22.7273	1936	85184	6.6332	99	10.1010	9801	970299	9.9499
45	22.2222	2025	91125	6.7082	**100**	10.0000	10000	1000000	10.0000
46	21.7391	2116	97336	6.7823	101	9.90099	10201	1030301	10.0499
47	21.2766	2209	103823	6.8557	102	9.80392	10404	1061208	10.0995
48	20.8333	2304	110592	6.9282	103	9.70874	10609	1092727	10.1489
49	20.4082	2401	117649	7.0000	104	9.61538	10816	1124864	10.1980
50	20.0000	2500	125000	7.0711	**105**	9.52381	11025	1157625	10.2470
51	19.6078	2601	132651	7.1414	106	9.43396	11236	1191016	10.2956
52	19.2308	2704	140608	7.2111	107	9.34579	11449	1225043	10.3441
53	18.8679	2809	148877	7.2801	108	9.25926	11664	1259712	10.3923
54	18.5185	2916	157464	7.3485	109	9.17431	11881	1295029	10.4403
55	18.1818	3025	166375	7.4162	**110**	9.09091	12100	1331000	10.4881
56	17.8571	3136	175616	7.4833	111	9.00901	12321	1367631	10.5357
57	17.5439	3249	185193	7.5498	112	8.92857	12544	1404928	10.5830
58	17.2414	3364	195112	7.6158	113	8.84956	12769	1442897	10.6301
59	16.9492	3481	205379	7.6811	114	8.77193	12996	1481544	10.6771
60	16.6667	3600	216000	7.7460	**115**	8.69565	13225	1520875	10.7238
61	16.3934	3721	226981	7.8102	116	8.62069	13456	1560896	10.7703
62	16.1290	3844	238328	7.8740	117	8.54701	13689	1601613	10.8167
63	15.8730	3969	250047	7.9373	118	8.47458	13924	1643032	10.8628
64	15.6250	4096	262144	8.0000	119	8.40336	14161	1685159	10.9087

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
120	8.33333	14400	1728000	10.9545	**175**	5.71429	30625	5359375	13.2288
121	8.26446	14641	1771561	11.0000	176	5.68182	30976	5451776	13.2665
122	8.19672	14884	1815848	11.0454	177	5.64972	31329	5545233	13.3041
123	8.13008	15129	1860867	11.0905	178	5.61798	31684	5639752	13.3417
124	8.06452	15376	1906624	11.1355	179	5.58659	32041	5735339	13.3791
125	8.00000	15625	1953125	11.1803	**180**	5.55556	32400	5832000	13.4164
126	7.93651	15876	2000376	11.2250	181	5.52486	32761	5929741	13.4536
127	7.87402	16129	2048383	11.2694	182	5.49451	33124	6028568	13.4907
128	7.81250	16384	2097152	11.3137	183	5.46448	33489	6128487	13.5277
129	7.75194	16641	2146689	11.3578	184	5.43478	33856	6229504	13.5647
130	7.69231	16900	2197000	11.4018	**185**	5.40541	34225	6331625	13.6015
131	7.63359	17161	2248091	11.4455	186	5.37634	34596	6434856	13.6382
132	7.57576	17424	2299968	11.4891	187	5.34759	34969	6539203	13.6748
133	7.51880	17689	2352637	11.5326	188	5.31915	35344	6644672	13.7113
134	7.46269	17956	2406104	11.5758	189	5.29101	35721	6751269	13.7477
135	7.40741	18225	2460375	11.6190	**190**	5.26316	36100	6859000	13.7840
136	7.35294	18496	2515456	11.6619	191	5.23560	36481	6967871	13.8203
137	7.29927	18769	2571353	11.7047	192	5.20833	36864	7077888	13.8564
138	7.24638	19044	2628072	11.7473	193	5.18135	37249	7189057	13.8924
139	7.19424	19321	2685619	11.7898	194	5.15464	37636	7301384	13.9284
140	7.14286	19600	2744000	11.8322	**195**	5.12821	38025	7414875	13.9642
141	7.09220	19881	2803221	11.8743	196	5.10204	38416	7529536	14.0000
142	7.04225	20164	2863288	11.9164	197	5.07614	38809	7645373	14.0357
143	6.99301	20449	2924207	11.9583	198	5.05051	39204	7762392	14.0712
144	6.94444	20736	2985984	12.0000	199	5.02513	39601	7880599	14.1067
145	6.89655	21025	3048625	12.0416	**200**	5.00000	40000	8000000	14.1421
146	6.84932	21316	3112136	12.0830	201	4.97512	40401	8120601	14.1774
147	6.80272	21609	3176523	12.1244	202	4.95050	40804	8242408	14.2127
148	6.75676	21904	3241792	12.1655	203	4.92611	41209	8365427	14.2478
149	6.71141	22201	3307949	12.2066	204	4.90196	41616	8489664	14.2829
150	6.66667	22500	3375000	12.2474	**205**	4.87805	42025	8615125	14.3178
151	6.62252	22801	3442951	12.2882	206	4.85437	42436	8741816	14.3527
152	6.57895	23104	3511808	12.3288	207	4.83092	42849	8869743	14.3875
153	6.53595	23409	3581577	12.3693	208	4.80769	43264	8998912	14.4222
154	6.49351	23716	3652264	12.4097	209	4.78469	43681	9129329	14.4568
155	6.45161	24025	3723875	12.4499	**210**	4.76190	44100	9261000	14.4914
156	6.41026	24336	3796416	12.4900	211	4.73934	44521	9393931	14.5258
157	6.36943	24649	3869893	12.5300	212	4.71698	44944	9528128	14.5602
158	6.32911	24964	3944312	12.5698	213	4.69484	45369	9663597	14.5945
159	6.28931	25281	4019679	12.6095	214	4.67290	45796	9800344	14.6287
160	6.25000	25600	4096000	12.6491	**215**	4.65116	46225	9938375	14.6629
161	6.21118	25921	4173281	12.6886	216	4.62963	46656	10077696	14.6969
162	6.17284	26244	4251528	12.7279	217	4.60829	47089	10218313	14.7309
163	6.13497	26569	4330747	12.7671	218	4.58716	47524	10360232	14.7648
164	6.09756	26896	4410944	12.8062	219	4.56621	47961	10503459	14.7986
165	6.06061	27225	4492125	12.8452	**220**	4.54545	48400	10648000	14.8324
166	6.02410	27556	4574296	12.8841	221	4.52489	48841	10793861	14.8661
167	5.98802	27889	4657463	12.9228	222	4.50450	49284	10941048	14.8997
168	5.95238	28224	4741632	12.9615	223	4.48430	49729	11089567	14.9332
169	5.91716	28561	4826809	13.0000	224	4.46429	50176	11239424	14.9666
170	5.88235	28900	4913000	13.0384	**225**	4.44444	50625	11390625	15.0000
171	5.84795	29241	5000211	13.0767	226	4.42478	51076	11543176	15.0333
172	5.81395	29584	5088448	13.1149	227	4.40529	51529	11697083	15.0665
173	5.78035	29929	5177717	13.1529	228	4.38596	51984	11852352	15.0997
174	5.74713	30276	5268024	13.1909	229	4.36681	52441	12008989	15.1327

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
230	4.34783	52900	12167000	15.1658	**285**	3.50877	81225	23149125	16.8819
231	4.32900	53361	12326391	15.1987	286	3.49650	81796	23393656	16.9115
232	4.31034	53824	12487168	15.2315	287	3.48432	82369	23639903	16.9411
233	4.29185	54289	12649337	15.2643	288	3.47222	82944	23887872	16.9706
234	4.27350	54756	12812904	15.2971	289	3.46021	83521	24137569	17.0000
235	4.25532	55225	12977875	15.3297	**290**	3.44828	84100	24389000	17.0294
236	4.23729	55696	13144256	15.3623	291	3.43643	84681	24642171	17.0587
237	4.21941	56169	13312053	15.3948	292	3.42466	85264	24897088	17.0880
238	4.20168	56644	13481272	15.4272	293	3.41297	85849	25153757	17.1172
239	4.18410	57121	13651919	15.4596	294	3.40136	86436	25412184	17.1464
240	4.16667	57600	13824000	15.4919	**295**	3.38983	87025	25672375	17.1756
241	4.14938	58081	13997521	15.5242	296	3.37838	87616	25934336	17.2047
242	4.13223	58564	14172488	15.5563	297	3.36700	88209	26198073	17.2337
243	4.11523	59049	14348907	15.5885	298	3.35570	88804	26463592	17.2627
244	4.09836	59536	14526784	15.6205	299	3.34448	89401	26730899	17.2916
245	4.08163	60025	14706125	15.6525	**300**	3.33333	90000	27000000	17.3205
246	4.06504	60516	14886936	15.6844	301	3.32226	90601	27270901	17.3494
247	4.04858	61009	15069223	15.7162	302	3.31126	91204	27543608	17.3781
248	4.03226	61504	15252992	15.7480	303	3.30033	91809	27818127	17.4069
249	4.01606	62001	15438249	15.7797	304	3.28947	92416	28094464	17.4356
250	4.00000	62500	15625000	15.8114	**305**	3.27869	93025	28372625	17.4642
251	3.98406	63001	15813251	15.8430	306	3.26797	93636	28652616	17.4929
252	3.96825	63504	16003008	15.8745	307	3.25733	94249	28934443	17.5214
253	3.95257	64009	16194277	15.9060	308	3.24675	94864	29218112	17.5499
254	3.93701	64516	16387064	15.9374	309	3.23625	95481	29503629	17.5784
255	3.92157	65025	16581375	15.9687	**310**	3.22581	96100	29791000	17.6068
256	3.90625	65536	16777216	16.0000	311	3.21543	96721	30080231	17.6352
257	3.89105	66049	16974593	16.0312	312	3.20513	97344	30371328	17.6635
258	3.87597	66564	17173512	16.0624	313	3.19489	97969	30664297	17.6918
259	3.86100	67081	17373979	16.0935	314	3.18471	98596	30959144	17.7200
260	3.84615	67600	17576000	16.1245	**315**	3.17460	99225	31255875	17.7482
261	3.83142	68121	17779581	16.1555	316	3.16456	99856	31554496	17.7764
262	3.81679	68644	17984728	16.1864	317	3.15457	100489	31855013	17.8045
263	3.80228	69169	18191447	16.2173	318	3.14465	101124	32157432	17.8326
264	3.78788	69696	18399744	16.2481	319	3.13480	101761	32461759	17.8606
265	3.77358	70225	18609625	16.2788	**320**	3.12500	102400	32768000	17.8885
266	3.75940	70756	18821096	16.3095	321	3.11526	103041	33076161	17.9165
267	3.74532	71289	19034163	16.3401	322	3.10559	103684	33386248	17.9444
268	3.73134	71824	19248832	16.3707	323	3.09598	104329	33698267	17.9722
269	3.71747	72361	19465109	16.4012	324	3.08642	104976	34012224	18.0000
270	3.70370	72900	19683000	16.4317	**325**	3.07692	105625	34328125	18.0278
271	3.69004	73441	19902511	16.4621	326	3.06748	106276	34645976	18.0555
272	3.67647	73984	20123648	16.4924	327	3.05810	106929	34965783	18.0831
273	3.66300	74529	20346417	16.5227	328	3.04878	107584	35287552	18.1108
274	3.64964	75076	20570824	16.5529	329	3.03951	108241	35611289	18.1384
275	3.63636	75625	20796875	16.5831	**330**	3.03030	108900	35937000	18.1659
276	3.62319	76176	21024576	16.6132	331	3.02115	109561	36264691	18.1934
277	3.61011	76729	21253933	16.6433	332	3.01205	110224	36594368	18.2209
278	3.59712	77284	21484952	16.6733	333	3.00300	110889	36926037	18.2483
279	3.58423	77841	21717639	16.7033	334	2.99401	111556	37259704	18.2757
280	3.57143	78400	21952000	16.7332	**335**	2.98507	112225	37595375	18.3030
281	3.55872	78961	22188041	16.7631	336	2.97619	112896	37933056	18.3303
282	3.54610	79524	22425768	16.7929	337	2.96736	113569	38272753	18.3576
283	3.53357	80089	22665187	16.8226	338	2.95858	114244	38614472	18.3848
284	3.52113	80656	22906304	16.8523	339	2.94985	114921	38958219	18.4120

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
340	2.94118	115600	39304000	18.4391	**395**	2.53165	156025	61629875	19.8746
341	2.93255	116281	39651821	18.4662	396	2.52525	156816	62099136	19.8997
342	2.92398	116964	40001688	18.4932	397	2.51889	157609	62570773	19.9249
343	2.91545	117649	40353607	18.5203	398	2.51256	158404	63044792	19.9499
344	2.90698	118336	40707584	18.5472	399	2.50627	159201	63521199	19.9750
345	2.89855	119025	41063625	18.5742	**400**	2.50000	160000	64000000	20.0000
346	2.89017	119716	41421736	18.6011	401	2.49377	160801	64481201	20.0250
347	2.88184	120409	41781923	18.6279	402	2.48756	161604	64964808	20.0499
348	2.87356	121104	42144192	18.6548	403	2.48139	162409	65450827	20.0749
349	2.86533	121801	42508549	18.6815	404	2.47525	163216	65939264	20.0998
350	2.85714	122500	42875000	18.7083	**405**	2.46914	164025	66430125	20.1246
351	2.84900	123201	43243551	18.7350	406	2.46305	164836	66923416	20.1494
352	2.84091	123904	43614208	18.7617	407	2.45700	165649	67419143	20.1742
353	2.83286	124609	43986977	18.7883	408	2.45098	166464	67917312	20.1990
354	2.82486	125316	44361864	18.8149	409	2.44499	167281	68417929	20.2237
355	2.81690	126025	44738875	18.8414	**410**	2.43902	168100	68921000	20.2485
356	2.80899	126736	45118016	18.8680	411	2.43309	168921	69426531	20.2731
357	2.80112	127449	45499293	18.8944	412	2.42718	169744	69934528	20.2978
358	2.79330	128164	45882712	18.9209	413	2.42131	170569	70444997	20.3224
359	2.78552	128881	46268279	18.9473	414	2.41546	171396	70957944	20.3470
360	2.77778	129600	46656000	18.9737	**415**	2.40964	172225	71473375	20.3715
361	2.77008	130321	47045881	19.0000	416	2.40385	173056	71991296	20.3961
362	2.76243	131044	47437928	19.0263	417	2.39808	173889	72511713	20.4206
363	2.75482	131769	47832147	19.0526	418	2.39234	174724	73034632	20.4450
364	2.74725	132496	48228544	19.0788	419	2.38663	175561	73560059	20.4695
365	2.73973	133225	48627125	19.1050	**420**	2.38095	176400	74088000	20.4939
366	2.73224	133956	49027896	19.1311	421	2.37530	177241	74618461	20.5183
367	2.72480	134689	49430863	19.1572	422	2.36967	178084	75151448	20.5426
368	2.71739	135424	49836032	19.1833	423	2.36407	178929	75686967	20.5670
369	2.71003	136161	50243409	19.2094	424	2.35849	179776	76225024	20.5913
370	2.70270	136900	50653000	19.2354	**425**	2.35294	180625	76765625	20.6155
371	2.69542	137641	51064811	19.2614	426	2.34742	181476	77308776	20.6398
372	2.68817	138384	51478848	19.2873	427	2.34192	182329	77854483	20.6640
373	2.68097	139129	51895117	19.3132	428	2.33645	183184	78402752	20.6882
374	2.67380	139876	52313624	19.3391	429	2.33100	184041	78953589	20.7123
375	2.66667	140625	52734375	19.3649	**430**	2.32558	184900	79507000	20.7364
376	2.65957	141376	53157376	19.3907	431	2.32019	185761	80062991	20.7605
377	2.65252	142129	53582633	19.4165	432	2.31481	186624	80621568	20.7846
378	2.64550	142884	54010152	19.4422	433	2.30947	187489	81182737	20.8087
379	2.63852	143641	54439939	19.4679	434	2.30415	188356	81746504	20.8327
380	2.63158	144400	54872000	19.4936	**435**	2.29885	189225	82312875	20.8567
381	2.62467	145161	55306341	19.5192	436	2.29358	190096	82881856	20.8806
382	2.61780	145924	55742968	19.5448	437	2.28833	190969	83453453	20.9045
383	2.61097	146689	56181887	19.5704	438	2.28311	191844	84027672	20.9284
384	2.60417	147456	56623104	19.5959	439	2.27790	192721	84604519	20.9523
385	2.59740	148225	57066625	19.6214	**440**	2.27273	193600	85184000	20.9762
386	2.59067	148996	57512456	19.6469	441	2.26757	194481	85766121	21.0000
387	2.58398	149769	57960603	19.6723	442	2.26244	195364	86350888	21.0238
388	2.57732	150544	58411072	19.6977	443	2.25734	196249	86938307	21.0476
389	2.57069	151321	58863869	19.7231	444	2.25225	197136	87528384	21.0713
390	2.56410	152100	59319000	19.7484	**445**	2.24719	198025	88121125	21.0950
391	2.55754	152881	59776471	19.7737	446	2.24215	198916	88716536	21.1187
392	2.55102	153664	60236288	19.7990	447	2.23714	199809	89314623	21.1424
393	2.54453	154449	60698457	19.8242	448	2.23214	200704	89915392	21.1660
394	2.53807	155236	61162984	19.8494	449	2.22717	201601	90518849	21.1896

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
450	2.22222	202500	91125000	21.2132	**505**	1.98020	255025	128787625	22.4722
451	2.21729	203401	91733851	21.2368	506	1.97628	256036	129554216	22.4944
452	2.21239	204304	92345408	21.2603	507	1.97239	257049	130323843	22.5167
453	2.20751	205209	92959677	21.2838	508	1.96850	258064	131096512	22.5389
454	2.20264	206116	93576664	21.3073	509	1.96464	259081	131872229	22.5610
455	2.19780	207025	94196375	21.3307	**510**	1.96078	260100	132651000	22.5832
456	2.19298	207936	94818816	21.3542	511	1.95695	261121	133432831	22.6053
457	2.18818	208849	95443993	21.3776	512	1.95312	262144	134217728	22.6274
458	2.18341	209764	96071912	21.4009	513	1.94932	263169	135005697	22.6495
459	2.17865	210681	96702579	21.4243	514	1.94553	264196	135796744	22.6716
460	2.17391	211600	97336000	21.4476	**515**	1.94175	265225	136590875	22.6936
461	2.16920	212521	97972181	21.4709	516	1.93798	266256	137388096	22.7156
462	2.16450	213444	98611128	21.4942	517	1.93424	267289	138188413	22.7376
463	2.15983	214369	99252847	21.5174	518	1.93050	268324	138991832	22.7596
464	2.15517	215296	99897344	21.5407	519	1.92678	269361	139798359	22.7816
465	2.15054	216225	100544625	21.5639	**520**	1.92308	270400	140608000	22.8035
466	2.14592	217156	101194696	21.5870	521	1.91939	271441	141420761	22.8254
467	2.14133	218089	101847563	21.6102	522	1.91571	272484	142236648	22.8473
468	2.13675	219024	102503232	21.6333	523	1.91205	273529	143055667	22.8692
469	2.13220	219961	103161709	21.6564	524	1.90840	274576	143877824	22.8910
470	2.12766	220900	103823000	21.6795	**525**	1.90476	275625	144703125	22.9129
471	2.12314	221841	104487111	21.7025	526	1.90114	276676	145531576	22.9347
472	2.11864	222784	105154048	21.7256	527	1.89753	277729	146363183	22.9565
473	2.11416	223729	105823817	21.7486	528	1.89394	278784	147197952	22.9783
474	2.10970	224676	106496424	21.7715	529	1.89036	279841	148035889	23.0000
475	2.10526	225625	107171875	21.7945	**530**	1.88679	280900	148877000	23.0217
476	2.10084	226576	107850176	21.8174	531	1.88324	281961	149721291	23.0434
477	2.09644	227529	108531333	21.8403	532	1.87970	283024	150568768	23.0651
478	2.09205	228484	109215352	21.8632	533	1.87617	284089	151419437	23.0868
479	2.08768	229441	109902239	21.8861	534	1.87266	285156	152273304	23.1084
480	2.08333	230400	110592000	21.9089	**535**	1.86916	286225	153130375	23.1301
481	2.07900	231361	111284641	21.9317	536	1.86567	287296	153990656	23.1517
482	2.07469	232324	111980168	21.9545	537	1.86220	288369	154854153	23.1733
483	2.07039	233289	112678587	21.9773	538	1.85874	289444	155720872	23.1948
484	2.06612	234256	113379904	22.0000	539	1.85529	290521	156590819	23.2164
485	2.06186	235225	114084125	22.0227	**540**	1.85185	291600	157464000	23.2379
486	2.05761	236196	114791256	22.0454	541	1.84843	292681	158340421	23.2594
487	2.05339	237169	115501303	22.0681	542	1.84502	293764	159220088	23.2809
488	2.04918	238144	116214272	22.0907	543	1.84162	294849	160103007	23.3024
489	2.04499	239121	116930169	22.1133	544	1.83824	295936	160989184	23.3238
490	2.04082	240100	117649000	22.1359	**545**	1.83486	297025	161878625	23.3452
491	2.03666	241081	118370771	22.1585	546	1.83150	298116	162771336	23.3666
492	2.03252	242064	119095488	22.1811	547	1.82815	299209	163667323	23.3880
493	2.02840	243049	119823157	22.2036	548	1.82482	300304	164566592	23.4094
494	2.02429	244036	120553784	22.2261	549	1.82149	301401	165469149	23.4307
495	2.02020	245025	121287375	22.2486	**550**	1.81818	302500	166375000	23.4521
496	2.01613	246016	122023936	22.2711	551	1.81488	303601	167284151	23.4734
497	2.01207	247009	122763473	22.2935	552	1.81159	304704	168196608	23.4947
498	2.00803	248004	123505992	22.3159	553	1.80832	305809	169112377	23.5160
499	2.00401	249001	124251499	22.3383	554	1.80505	306916	170031464	23.5372
500	2.00000	250000	125000000	22.3607	**555**	1.80180	308025	170953875	23.5584
501	1.99601	251001	125751501	22.3830	556	1.79856	309136	171879616	23.5797
502	1.99203	252004	126506008	22.4054	557	1.79533	310249	172808693	23.6008
503	1.98807	253009	127263527	22.4277	558	1.79211	311364	173741112	23.6220
504	1.98413	254016	128024064	22.4499	559	1.78891	312481	174676879	23.6432

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
560	1.78571	313600	175616000	23.6643	**615**	1.62602	378225	232608375	24.7992
561	1.78253	314721	176558481	23.6854	616	1.62338	379456	233744896	24.8193
562	1.77936	315844	177504328	23.7065	617	1.62075	380689	234885113	24.8395
563	1.77620	316969	178453547	23.7276	618	1.61812	381924	236029032	24.8596
564	1.77305	318096	179406144	23.7487	619	1.61551	383161	237176659	24.8797
565	1.76991	319225	180362125	23.7697	**620**	1.61290	384400	238328000	24.8998
566	1.76678	320356	181321496	23.7908	621	1.61031	385641	239483061	24.9199
567	1.76367	321489	182284263	23.8118	622	1.60772	386884	240641848	24.9399
568	1.76056	322624	183250432	23.8328	623	1.60514	388129	241804367	24.9600
569	1.75747	323761	184220009	23.8537	624	1.60256	389376	242970624	24.9800
570	1.75439	324900	185193000	23.8747	**625**	1.60000	390625	244140625	25.0000
571	1.75131	326041	186169411	23.8956	626	1.59744	391876	245314376	25.0200
572	1.74825	327184	187149248	23.9165	627	1.59490	393129	246491883	25.0400
573	1.74520	328329	188132517	23.9374	628	1.59236	394384	247673152	25.0599
574	1.74216	329476	189119224	23.9583	629	1.58983	395641	248858189	25.0799
575	1.73913	330625	190109375	23.9792	**630**	1.58730	396900	250047000	25.0998
576	1.73611	331776	191102976	24.0000	631	1.58479	398161	251239591	25.1197
577	1.73310	332929	192100033	24.0208	632	1.58228	399424	252435968	25.1396
578	1.73010	334084	193100552	24.0416	633	1.57978	400689	253636137	25.1595
579	1.72712	335241	194104539	24.0624	634	1.57729	401956	254840104	25.1794
580	1.72414	336400	195112000	24.0832	**635**	1.57480	403225	256047875	25.1992
581	1.72117	337561	196122941	24.1039	636	1.57233	404496	257259456	25.2190
582	1.71821	338724	197137368	24.1247	637	1.56986	405769	258474853	25.2389
583	1.71527	339889	198155287	24.1454	638	1.56740	407044	259694072	25.2587
584	1.71233	341056	199176704	24.1661	639	1.56495	408321	260917119	25.2784
585	1.70940	342225	200201625	24.1868	**640**	1.56250	409600	262144000	25.2982
586	1.70648	343396	201230056	24.2074	641	1.56006	410881	263374721	25.3180
587	1.70358	344569	202262003	24.2281	642	1.55763	412164	264609288	25.3377
588	1.70068	345744	203297472	24.2487	643	1.55521	413449	265847707	25.3574
589	1.69779	346921	204336469	24.2693	644	1.55280	414736	267089984	25.3772
590	1.69492	348100	205379000	24.2899	**645**	1.55039	416025	268336125	25.3969
591	1.69205	349281	206425071	24.3105	646	1.54799	417316	269586136	25.4165
592	1.68919	350464	207474688	24.3311	647	1.54560	418609	270840023	25.4362
593	1.68634	351649	208527857	24.3516	648	1.54321	419904	272097792	25.4558
594	1.68350	352836	209584584	24.3721	649	1.54083	421201	273359449	25.4755
595	1.68067	354025	210644875	24.3926	**650**	1.53846	422500	274625000	25.4951
596	1.67785	355216	211708736	24.4131	651	1.53610	423801	275894451	25.5147
597	1.67504	356409	212776173	24.4336	652	1.53374	425104	277167808	25.5343
598	1.67224	357604	213847192	24.4540	653	1.53139	426409	278445077	25.5539
599	1.66945	358801	214921799	24.4745	654	1.52905	427716	279726264	25.5734
600	1.66667	360000	216000000	24.4949	**655**	1.52672	429025	281011375	25.5930
601	1.66389	361201	217081801	24.5153	656	1.52439	430336	282300416	25.6125
602	1.66113	362404	218167208	24.5357	657	1.52207	431649	283593393	25.6320
603	1.65837	363609	219256227	24.5561	658	1.51976	432964	284890312	25.6515
604	1.65563	364816	220348864	24.5764	659	1.51745	434281	286191179	25.6710
605	1.65289	366025	221445125	24.5967	**660**	1.51515	435600	287496000	25.6905
606	1.65017	367236	222545016	24.6171	661	1.51286	436921	288804781	25.7099
607	1.64745	368449	223648543	24.6374	662	1.51057	438244	290117528	25.7294
608	1.64474	369664	224755712	24.6577	663	1.50830	439569	291434247	25.7488
609	1.64204	370881	225866529	24.6779	664	1.50602	440896	292754944	25.7682
610	1.63934	372100	226981000	24.6982	**665**	1.50376	442225	294079625	25.7876
611	1.63666	373321	228099131	24.7184	666	1.50150	443556	295408296	25.8070
612	1.63399	374544	229220928	24.7386	667	1.49925	444889	296740963	25.8263
613	1.63132	375769	230346397	24.7588	668	1.49701	446224	298077632	25.8457
614	1.62866	376996	231475544	24.7790	669	1.49477	447561	299418309	25.8650

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
670	1.49254	448900	300763000	25.8844	**725**	1.37931	525625	381078125	26.9258
671	1.49031	450241	302111711	25.9037	726	1.37741	527076	382657176	26.9444
672	1.48810	451584	303464448	25.9230	727	1.37552	528529	384240583	26.9629
673	1.48588	452929	304821217	25.9422	728	1.37363	529984	385828352	26.9815
674	1.48368	454276	306182024	25.9615	729	1.37174	531441	387420489	27.0000
675	1.48148	455625	307546875	25.9808	**730**	1.36986	532900	389017000	27.0185
676	1.47929	456976	308915776	26.0000	731	1.36799	534361	390617891	27.0370
677	1.47710	458329	310288733	26.0192	732	1.36612	535824	392223168	27.0555
678	1.47493	459684	311665752	26.0384	733	1.36426	537289	393832837	27.0740
679	1.47275	461041	313046839	26.0576	734	1.36240	538756	395446904	27.0924
680	1.47059	462400	314432000	26.0768	**735**	1.36054	540225	397065375	27.1109
681	1.46843	463761	315821241	26.0960	736	1.35870	541696	398688256	27.1293
682	1.46628	465124	317214568	26.1151	737	1.35685	543169	400315553	27.1477
683	1.46413	466489	318611987	26.1343	738	1.35501	544644	401947272	27.1662
684	1.46199	467856	320013504	26.1534	739	1.35318	546121	403583419	27.1846
685	1.45985	469225	321419125	26.1725	**740**	1.35135	547600	405224000	27.2029
686	1.45773	470596	322828856	26.1916	741	1.34953	549081	406869021	27.2213
687	1.45560	471969	324242703	26.2107	742	1.34771	550564	408518488	27.2397
688	1.45349	473344	325660672	26.2298	743	1.34590	552049	410172407	27.2580
689	1.45138	474721	327082769	26.2488	744	1.34409	553536	411830784	27.2764
690	1.44928	476100	328509000	26.2679	**745**	1.34228	555025	413493625	27.2947
691	1.44718	477481	329939371	26.2869	746	1.34048	556516	415160936	27.3130
692	1.44509	478864	331373888	26.3059	747	1.33869	558009	416832723	27.3313
693	1.44300	480249	332812557	26.3249	748	1.33690	559504	418508992	27.3496
694	1.44092	481636	334255384	26.3439	749	1.33511	561001	420189749	27.3679
695	1.43885	483025	335702375	26.3629	**750**	1.33333	562500	421875000	27.3861
696	1.43678	484416	337153536	26.3818	751	1.33156	564001	423564751	27.4044
697	1.43472	485809	338608873	26.4008	752	1.32979	565504	425259008	27.4226
698	1.43266	487204	340068392	26.4197	753	1.32802	567009	426957777	27.4408
699	1.43062	488601	341532099	26.4386	754	1.32626	568516	428661064	27.4591
700	1.42857	490000	343000000	26.4575	**755**	1.32450	570025	430368875	27.4773
701	1.42653	491401	344472101	26.4764	756	1.32275	571536	432081216	27.4955
702	1.42450	492804	345948408	26.4953	757	1.32100	573049	433798093	27.5136
703	1.42248	494209	347428927	26.5141	758	1.31926	574564	435519512	27.5318
704	1.42045	495616	348913664	26.5330	759	1.31752	576081	437245479	27.5500
705	1.41844	497025	350402625	26.5518	**760**	1.31579	577600	438976000	27.5681
706	1.41643	498436	351895816	26.5707	761	1.31406	579121	440711081	27.5862
707	1.41443	499849	353393243	26.5895	762	1.31234	580644	442450728	27.6043
708	1.41243	501264	354894912	26.6083	763	1.31062	582169	444194947	27.6225
709	1.41044	502681	356400829	26.6271	764	1.30890	583696	445943744	27.6405
710	1.40845	504100	357911000	26.6458	**765**	1.30719	585225	447697125	27.6586
711	1.40647	505521	359425431	26.6646	766	1.30548	586756	449455096	27.6767
712	1.40449	506944	360944128	26.6833	767	1.30378	588289	451217663	27.6948
713	1.40252	508369	362467097	26.7021	768	1.30208	589824	452984832	27.7128
714	1.40056	509796	363994344	26.7208	769	1.30039	591361	454756609	27.7308
715	1.39860	511225	365525875	26.7395	**770**	1.29870	592900	456533000	27.7489
716	1.39665	512656	367061696	26.7582	771	1.29702	594441	458314011	27.7669
717	1.39470	514089	368601813	26.7769	772	1.29534	595984	460099648	27.7849
718	1.39276	515524	370146232	26.7955	773	1.29366	597529	461889917	27.8029
719	1.39082	516961	371694959	26.8142	774	1.29199	599076	463684824	27.8209
720	1.38889	518400	373248000	26.8328	**775**	1.29032	600625	465484375	27.8388
721	1.38696	519841	374805361	26.8514	776	1.28866	602176	467288576	27.8568
722	1.38504	521284	376367048	26.8701	777	1.28700	603729	469097433	27.8747
723	1.38313	522729	377933067	26.8887	778	1.28535	605284	470910952	27.8927
724	1.38122	524176	379503424	26.9072	779	1.28370	606841	472729139	27.9106

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
780	1.28205	608400	474552000	27.9285	**835**	1.19760	697225	582182875	28.8964
781	1.28041	609961	476379541	27.9464	836	1.19617	698896	584277056	28.9137
782	1.27877	611524	478211768	27.9643	837	1.19474	700569	586376253	28.9310
783	1.27714	613089	480048687	27.9821	838	1.19332	702244	588480472	28.9482
784	1.27551	614656	481890304	28.0000	839	1.19190	703921	590589719	28.9655
785	1.27389	616225	483736625	28.0179	**840**	1.19048	705600	592704000	28.9828
786	1.27226	617796	485587656	28.0357	841	1.18906	707281	594823321	29.0000
787	1.27065	619369	487443403	28.0535	842	1.18765	708964	596947688	29.0172
788	1.26904	620944	489303872	28.0713	843	1.18624	710649	599077107	29.0345
789	1.26743	622521	491169069	28.0891	844	1.18483	712336	601211584	29.0517
790	1.26582	624100	493039000	28.1069	**845**	1.18343	714025	603351125	29.0689
791	1.26422	625681	494913671	28.1247	846	1.18203	715716	605495736	29.0861
792	1.26263	627264	496793088	28.1425	847	1.18064	717409	607645423	29.1033
793	1.26103	628849	498677257	28.1603	848	1.17925	719104	609800192	29.1204
794	1.25945	630436	500566184	28.1780	849	1.17786	720801	611960049	29.1376
795	1.25786	632025	502459875	28.1957	**850**	1.17647	722500	614125000	29.1548
796	1.25628	633616	504358336	28.2135	851	1.17509	724201	616295051	29.1719
797	1.25471	635209	506261573	28.2312	852	1.17371	725904	618470208	29.1890
798	1.25313	636804	508169592	28.2489	853	1.17233	727609	620650477	29.2062
799	1.25156	638401	510082399	28.2666	854	1.17096	729316	622835864	29.2233
800	1.25000	640000	512000000	28.2843	**855**	1.16959	731025	625026375	29.2404
801	1.24844	641601	513922401	28.3019	856	1.16822	732736	627222016	29.2575
802	1.24688	643204	515849608	28.3196	857	1.16686	734449	629422793	29.2746
803	1.24533	644809	517781627	28.3373	858	1.16550	736164	631628712	29.2916
804	1.24378	646416	519718464	28.3549	859	1.16414	737881	633839779	29.3087
805	1.24224	648025	521660125	28.3725	**860**	1.16279	739600	636056000	29.3258
806	1.24069	649636	523606616	28.3901	861	1.16144	741321	638277381	29.3428
807	1.23916	651249	525557943	28.4077	862	1.16009	743044	640503928	29.3598
808	1.23762	652864	527514112	28.4253	863	1.15875	744769	642735647	29.3769
809	1.23609	654481	529475129	28.4429	864	1.15741	746496	644972544	29.3939
810	1.23457	656100	531441000	28.4605	**865**	1.15607	748225	647214625	29.4109
811	1.23305	657721	533411731	28.4781	866	1.15473	749956	649461896	29.4279
812	1.23153	659344	535387328	28.4956	867	1.15340	751689	651714363	29.4449
813	1.23001	660969	537367797	28.5132	868	1.15207	753424	653972032	29.4618
814	1.22850	662596	539353144	28.5307	869	1.15075	755161	656234909	29.4788
815	1.22699	664225	541343375	28.5482	**870**	1.14943	756900	658503000	29.4958
816	1.22549	665856	543338496	28.5657	871	1.14811	758641	660776311	29.5127
817	1.22399	667489	545338513	28.5832	872	1.14679	760384	663054848	29.5296
818	1.22249	669124	547343432	28.6007	873	1.14548	762129	665338617	29.5466
819	1.22100	670761	549353259	28.6182	874	1.14416	763876	667627624	29.5635
820	1.21951	672400	551368000	28.6356	**875**	1.14286	765625	669921875	29.5804
821	1.21803	674041	553387661	28.6531	876	1.14155	767376	672221376	29.5973
822	1.21655	675684	555412248	28.6705	877	1.14025	769129	674526133	29.6142
823	1.21507	677329	557441767	28.6880	878	1.13895	770884	676836152	29.6311
824	1.21359	678976	559476224	28.7054	879	1.13766	772641	679151439	29.6479
825	1.21212	680625	561515625	28.7228	**880**	1.13636	774400	681472000	29.6648
826	1.21065	682276	563559976	28.7402	881	1.13507	776161	683797841	29.6816
827	1.20919	683929	565609283	28.7576	882	1.13379	777924	686128968	29.6985
828	1.20773	685584	567663552	28.7750	883	1.13250	779689	688465387	29.7153
829	1.20627	687241	569722789	28.7924	884	1.13122	781456	690807104	29.7321
830	1.20482	688900	571787000	28.8097	**885**	1.12994	783225	693154125	29.7489
831	1.20337	690561	573856191	28.8271	886	1.12867	784996	695506456	29.7658
832	1.20192	692224	575930368	28.8444	887	1.12740	786769	697864103	29.7825
833	1.20048	693889	578009537	28.8617	888	1.12613	788544	700227072	29.7993
834	1.19904	695556	580093704	28.8791	889	1.12486	790321	702595369	29.8161

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
890	1.12360	792100	704969000	29.8329	**945**	1.05820	893025	843908625	30.7409
891	1.12233	793881	707347971	29.8496	946	1.05708	894916	846590536	30.7571
892	1.12108	795664	709732288	29.8664	947	1.05597	896809	849278123	30.7734
893	1.11982	797449	712121957	29.8831	948	1.05485	898704	851971392	30.7896
894	1.11857	799236	714516984	29.8998	949	1.05374	900601	854670349	30.8058
895	1.11732	801025	716917375	29.9166	**950**	1.05263	902500	857375000	30.8221
896	1.11607	802816	719323136	29.9333	951	1.05152	904401	860085351	30.8383
897	1.11483	804609	721734273	29.9500	952	1.05042	906304	862801408	30.8545
898	1.11359	806404	724150792	29.9666	953	1.04932	908209	865523177	30.8707
899	1.11235	808201	726572699	29.9833	954	1.04822	910116	868250664	30.8869
900	1.11111	810000	729000000	30.0000	**955**	1.04712	912025	870983875	30.9031
901	1.10988	811801	731432701	30.0167	956	1.04603	913936	873722816	30.9192
902	1.10865	813604	733870808	30.0333	957	1.04493	915849	876467493	30.9354
903	1.10742	815409	736314327	30.0500	958	1.04384	917764	879217912	30.9516
904	1.10619	817216	738763264	30.0666	959	1.04275	919681	881974079	30.9677
905	1.10497	819025	741217625	30.0832	**960**	1.04167	921600	884736000	30.9839
906	1.10375	820836	743677416	30.0998	961	1.04058	923521	887503681	31.0000
907	1.10254	822649	746142643	30.1164	962	1.03950	925444	890277128	31.0161
908	1.10132	824464	748613312	30.1330	963	1.03842	927369	893056347	31.0322
909	1.10011	826281	751089429	30.1496	964	1.03734	929296	895841344	31.0483
910	1.09890	828100	753571000	30.1662	**965**	1.03627	931225	898632125	31.0644
911	1.09769	829921	756058031	30.1828	966	1.03520	933156	901428696	31.0805
912	1.09649	831744	758550528	30.1993	967	1.03413	935089	904231063	31.0966
913	1.09529	833569	761048497	30.2159	968	1.03306	937024	907039232	31.1127
914	1.09409	835396	763551944	30.2324	969	1.03199	938961	909853209	31.1288
915	1.09290	837225	766060875	30.2490	**970**	1.03093	940900	912673000	31.1448
916	1.09170	839056	768575296	30.2655	971	1.02987	942841	915498611	31.1609
917	1.09051	840889	771095213	30.2820	972	1.02881	944784	918330048	31.1769
918	1.08932	842724	773620632	30.2985	973	1.02775	946729	921167317	31.1929
919	1.08814	844561	776151559	30.3150	974	1.02669	948676	924010424	31.2090
920	1.08696	846400	778688000	30.3315	**975**	1.02564	950625	926859375	31.2250
921	1.08578	848241	781229961	30.3480	976	1.02459	952576	929714176	31.2410
922	1.08460	850084	783777448	30.3645	977	1.02354	954529	932574833	31.2570
923	1.08342	851929	786330467	30.3809	978	1.02249	956484	935441352	31.2730
924	1.08225	853776	788889024	30.3974	979	1.02145	958441	938313739	31.2890
925	1.08108	855625	791453125	30.4138	**980**	1.02041	960400	941192000	31.3050
926	1.07991	857476	794022776	30.4302	981	1.01937	962361	944076141	31.3209
927	1.07875	859329	796597983	30.4467	982	1.01833	964324	946966168	31.3369
928	1.07759	861184	799178752	30.4631	983	1.01729	966289	949862087	31.3528
929	1.07643	863041	801765089	30.4795	984	1.01626	968256	952763904	31.3688
930	1.07527	864900	804357000	30.4959	**985**	1.01523	970225	955671625	31.3847
931	1.07411	866761	806954491	30.5123	986	1.01420	972196	958585256	31.4006
932	1.07296	868624	809557568	30.5287	987	1.01317	974169	961504803	31.4166
933	1.07181	870489	812166237	30.5450	988	1.01215	976144	964430272	31.4325
934	1.07066	872356	814780504	30.5614	989	1.01112	978121	967361669	31.4484
935	1.06952	874225	817400375	30.5778	**990**	1.01010	980100	970299000	31.4643
936	1.06838	876096	820025856	30.5941	991	1.00908	982081	973242271	31.4802
937	1.06724	877969	822656953	30.6105	992	1.00806	984064	976191488	31.4960
938	1.06610	879844	825293672	30.6268	993	1.00705	986049	979146657	31.5119
939	1.06496	881721	827936019	30.6431	994	1.00604	988036	982107784	31.5278
940	1.06383	883600	830584000	30.6594	**995**	1.00503	990025	985074875	31.5436
941	1.06270	885481	833237621	30.6757	996	1.00402	992016	988047936	31.5595
942	1.06157	887364	835896888	30.6920	997	1.00301	994009	991026973	31.5753
943	1.06045	889249	838561807	30.7083	998	1.00200	996004	994011992	31.5911
944	1.05932	891136	841232384	30.7246	999	1.00100	998001	997002999	31.6070

TABLE 10

LOGARITHMS

N.	0	1	2	3	4	5	6	7	8	9	10
100	0000	0004	0009	0013	0017	0022	0026	0030	0035	0039	0043
101	0043	0048	0052	0056	0060	0065	0069	0073	0077	0082	0086
102	0086	0090	0095	0099	0103	0107	0111	0116	0120	0124	0128
103	0128	0133	0137	0141	0145	0149	0154	0158	0162	0166	0170
104	0170	0175	0179	0183	0187	0191	0195	0199	0204	0208	0212
105	0212	0216	0220	0224	0228	0233	0237	0241	0245	0249	0253
106	0253	0257	0261	0265	0269	0273	0278	0282	0286	0290	0294
107	0294	0298	0302	0306	0310	0314	0318	0322	0326	0330	0334
108	0334	0338	0342	0346	0350	0354	0358	0362	0366	0370	0374
109	0374	0378	0382	0386	0390	0394	0398	0402	0406	0410	0414
110	0414	0418	0422	0426	0430	0434	0438	0441	0445	0449	0453
111	0453	0457	0461	0465	0469	0473	0477	0481	0484	0488	0492
112	0492	0496	0500	0504	0508	0512	0515	0519	0523	0527	0531
113	0531	0535	0538	0542	0546	0550	0554	0558	0561	0565	0569
114	0569	0573	0577	0580	0584	0588	0592	0596	0599	0603	0607
115	0607	0611	0615	0618	0622	0626	0630	0633	0637	0641	0645
116	0645	0648	0652	0656	0660	0663	0667	0671	0674	0678	0682
117	0682	0686	0689	0693	0697	0700	0704	0708	0711	0715	0719
118	0719	0722	0726	0730	0734	0737	0741	0745	0748	0752	0755
119	0755	0759	0763	0766	0770	0774	0777	0781	0785	0788	0792
120	0792	0795	0799	0803	0806	0810	0813	0817	0821	0824	0828
121	0828	0831	0835	0839	0842	0846	0849	0853	0856	0860	0864
122	0864	0867	0871	0874	0878	0881	0885	0888	0892	0896	0899
123	0899	0903	0906	0910	0913	0917	0920	0924	0927	0931	0934
124	0934	0938	0941	0945	0948	0952	0955	0959	0962	0966	0969
125	0969	0973	0976	0980	0983	0986	0990	0993	0997	1000	1004
126	1004	1007	1011	1014	1017	1021	1024	1028	1031	1035	1038
127	1038	1041	1045	1048	1052	1055	1059	1062	1065	1069	1072
128	1072	1075	1079	1082	1086	1089	1092	1096	1099	1103	1106
129	1106	1109	1113	1116	1119	1123	1126	1129	1133	1136	1139
130	1139	1143	1146	1149	1153	1156	1159	1163	1166	1169	1173
131	1173	1176	1179	1183	1186	1189	1193	1196	1199	1202	1206
132	1206	1209	1212	1216	1219	1222	1225	1229	1232	1235	1239
133	1239	1242	1245	1248	1252	1255	1258	1261	1265	1268	1271
134	1271	1274	1278	1281	1284	1287	1290	1294	1297	1300	1303
135	1303	1307	1310	1313	1316	1319	1323	1326	1329	1332	1335
136	1335	1339	1342	1345	1348	1351	1355	1358	1361	1364	1367
137	1367	1370	1374	1377	1380	1383	1386	1389	1392	1396	1399
138	1399	1402	1405	1408	1411	1414	1418	1421	1424	1427	1430
139	1430	1433	1436	1440	1443	1446	1449	1452	1455	1458	1461
140	1461	1464	1467	1471	1474	1477	1480	1483	1486	1489	1492
141	1492	1495	1498	1501	1504	1508	1511	1514	1517	1520	1523
142	1523	1526	1529	1532	1535	1538	1541	1544	1547	1550	1553
143	1553	1556	1559	1562	1565	1569	1572	1575	1578	1581	1584
144	1584	1587	1590	1593	1596	1599	1602	1605	1608	1611	1614
145	1614	1617	1620	1623	1626	1629	1632	1635	1638	1641	1644
146	1644	1647	1649	1652	1655	1658	1661	1664	1667	1670	1673
147	1673	1676	1679	1682	1685	1688	1691	1694	1697	1700	1703
148	1703	1706	1708	1711	1714	1717	1720	1723	1726	1729	1732
149	1732	1735	1738	1741	1744	1746	1749	1752	1755	1758	1761

LOGARITHMS

N.	0	1	2	3	4	5	6	7	8	9	10
150	1761	1764	1767	1770	1772	1775	1778	1781	1784	1787	1790
151	1790	1793	1796	1798	1801	1804	1807	1810	1813	1816	1818
152	1818	1821	1824	1827	1830	1833	1836	1838	1841	1844	1847
153	1847	1850	1853	1855	1858	1861	1864	1867	1870	1872	1875
154	1875	1878	1881	1884	1886	1889	1892	1895	1898	1901	1903
155	1903	1906	1909	1912	1915	1917	1920	1923	1926	1928	1931
156	1931	1934	1937	1940	1942	1945	1948	1951	1953	1956	1959
157	1959	1962	1965	1967	1970	1973	1976	1978	1981	1984	1987
158	1987	1989	1992	1995	1998	2000	2003	2006	2009	2011	2014
159	2014	2017	2019	2022	2025	2028	2030	2033	2036	2038	2041
160	2041	2044	2047	2049	2052	2055	2057	2060	2063	2066	2068
161	2068	2071	2074	2076	2079	2082	2084	2087	2090	2092	2095
162	2095	2098	2101	2103	2106	2109	2111	2114	2117	2119	2122
163	2122	2125	2127	2130	2133	2135	2138	2140	2143	2146	2148
164	2148	2151	2154	2156	2159	2162	2164	2167	2170	2172	2175
165	2175	2177	2180	2183	2185	2188	2191	2193	2196	2198	2201
166	2201	2204	2206	2209	2212	2214	2217	2219	2222	2225	2227
167	2227	2230	2232	2235	2238	2240	2243	2245	2248	2251	2253
168	2253	2256	2258	2261	2263	2266	2269	2271	2274	2276	2279
169	2279	2281	2284	2287	2289	2292	2294	2297	2299	2302	2304
170	2304	2307	2310	2312	2315	2317	2320	2322	2325	2327	2330
171	2330	2333	2335	2338	2340	2343	2345	2348	2350	2353	2355
172	2355	2358	2360	2363	2365	2368	2370	2373	2375	2378	2380
173	2380	2383	2385	2388	2390	2393	2395	2398	2400	2403	2405
174	2405	2408	2410	2413	2415	2418	2420	2423	2425	2428	2430
175	2430	2433	2435	2438	2440	2443	2445	2448	2450	2453	2455
176	2455	2458	2460	2463	2465	2467	2470	2472	2475	2477	2480
177	2480	2482	2485	2487	2490	2492	2494	2497	2499	2502	2504
178	2504	2507	2509	2512	2514	2516	2519	2521	2524	2526	2529
179	2529	2531	2533	2536	2538	2541	2543	2545	2548	2550	2553
180	2553	2555	2558	2560	2562	2565	2567	2570	2572	2574	2577
181	2577	2579	2582	2584	2586	2589	2591	2594	2596	2598	2601
182	2601	2603	2605	2608	2610	2613	2615	2617	2620	2622	2625
183	2625	2627	2629	2632	2634	2636	2639	2641	2643	2646	2648
184	2648	2651	2653	2655	2658	2660	2662	2665	2667	2669	2672
185	2672	2674	2676	2679	2681	2683	2686	2688	2690	2693	2695
186	2695	2697	2700	2702	2704	2707	2709	2711	2714	2716	2718
187	2718	2721	2723	2725	2728	2730	2732	2735	2737	2739	2742
188	2742	2744	2746	2749	2751	2753	2755	2758	2760	2762	2765
189	2765	2767	2769	2772	2774	2776	2778	2781	2783	2785	2788
190	2788	2790	2792	2794	2797	2799	2801	2804	2806	2808	2810
191	2810	2813	2815	2817	2819	2822	2824	2826	2828	2831	2833
192	2833	2835	2838	2840	2842	2844	2847	2849	2851	2853	2856
193	2856	2858	2860	2862	2865	2867	2869	2871	2874	2876	2878
194	2878	2880	2882	2885	2887	2889	2891	2894	2896	2898	2900
195	2900	2903	2905	2907	2909	2911	2914	2916	2918	2920	2923
196	2923	2925	2927	2929	2931	2934	2936	2938	2940	2942	2945
197	2945	2947	2949	2951	2953	2956	2958	2960	2962	2964	2967
198	2967	2969	2971	2973	2975	2978	2980	2982	2984	2986	2989
199	2989	2991	2993	2995	2997	2999	3002	3004	3006	3008	3010

LOGARITHMS

N	0	1	2	3	4	5	6	7	8	9	P. P. 1	2	3	4	5
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	5	7	9
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	6
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4

LOGARITHMS

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55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	3	3
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2

ANTILOGARITHMS

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.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1
.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2
.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2
.27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3
.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3
.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3
.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4

ANTILOGARITHMS

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.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4
.59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	10
.900	7943	7945	7947	7949	7951	7952	7954	7956	7958	7960	7962
.901	7962	7963	7965	7967	7969	7971	7973	7974	7976	7978	7980
.902	7980	7982	7984	7985	7987	7989	7991	7993	7995	7997	7998
.903	7998	8000	8002	8004	8006	8008	8009	8011	8013	8015	8017
.904	8017	8019	8020	8022	8024	8026	8028	8030	8032	8033	8035
.905	8035	8037	8039	8041	8043	8045	8046	8048	8050	8052	8054
.906	8054	8056	8057	8059	8061	8063	8065	8067	8069	8070	8072
.907	8072	8074	8076	8078	8080	8082	8084	8085	8087	8089	8091
.908	8091	8093	8095	8097	8098	8100	8102	8104	8106	8108	8110
.909	8110	8111	8113	8115	8117	8119	8121	8123	8125	8126	8128
.910	8128	8130	8132	8134	8136	8138	8140	8141	8143	8145	8147
.911	8147	8149	8151	8153	8155	8156	8158	8160	8162	8164	8166
.912	8166	8168	8170	8171	8173	8175	8177	8179	8181	8183	8185
.913	8185	8187	8188	8190	8192	8194	8196	8198	8200	8202	8204
.914	8204	8205	8207	8209	8211	8213	8215	8217	8219	8221	8222
.915	8222	8224	8226	8228	8230	8232	8234	8236	8238	8239	8241
.916	8241	8243	8245	8247	8249	8251	8253	8255	8257	8258	8260
.917	8260	8262	8264	8266	8268	8270	8272	8274	8276	8278	8279
.918	8279	8281	8283	8285	8287	8289	8291	8293	8295	8297	8299
.919	8299	8300	8302	8304	8306	8308	8310	8312	8314	8316	8318
.920	8318	8320	8321	8323	8325	8327	8329	8331	8333	8335	8337
.921	8337	8339	8341	8343	8344	8346	8348	8350	8352	8354	8356
.922	8356	8358	8360	8362	8364	8366	8368	8370	8371	8373	8375
.923	8375	8377	8379	8381	8383	8385	8387	8389	8391	8393	8395
.924	8395	8397	8398	8400	8402	8404	8406	8408	8410	8412	8414
.925	8414	8416	8418	8420	8422	8424	8426	8428	8429	8431	8433
.926	8433	8435	8437	8439	8441	8443	8445	8447	8449	8451	8453
.927	8453	8455	8457	8459	8461	8463	8464	8466	8468	8470	8472
.928	8472	8474	8476	8478	8480	8482	8484	8486	8488	8490	8492
.929	8492	8494	8496	8498	8500	8502	8504	8506	8507	8509	8511
.930	8511	8513	8515	8517	8519	8521	8523	8525	8527	8529	8531
.931	8531	8533	8535	8537	8539	8541	8543	8545	8547	8549	8551
.932	8551	8553	8555	8557	8559	8561	8562	8564	8566	8568	8570
.933	8570	8572	8574	8576	8578	8580	8582	8584	8586	8588	8590
.934	8590	8592	8594	8596	8598	8600	8602	8604	8606	8608	8610
.935	8610	8612	8614	8616	8618	8620	8622	8624	8626	8628	8630
.936	8630	8632	8634	8636	8638	8640	8642	8644	8646	8648	8650
.937	8650	8652	8654	8656	8658	8660	8662	8664	8666	8668	8670
.938	8670	8672	8674	8676	8678	8680	8682	8684	8686	8688	8690
.939	8690	8692	8694	8696	8698	8700	8702	8704	8706	8708	8710
.940	8710	8712	8714	8716	8718	8720	8722	8724	8726	8728	8730
.941	8730	8732	8734	8736	8738	8740	8742	8744	8746	8748	8750
.942	8750	8752	8754	8756	8758	8760	8762	8764	8766	8768	8770
.943	8770	8772	8774	8776	8778	8780	8782	8784	8786	8788	8790
.944	8790	8792	8794	8796	8798	8800	8802	8804	8806	8808	8810
.945	8810	8813	8815	8817	8819	8821	8823	8825	8827	8829	8831
.946	8831	8833	8835	8837	8839	8841	8843	8845	8847	8849	8851
.947	8851	8853	8855	8857	8859	8861	8863	8865	8867	8870	8872
.948	8872	8874	8876	8878	8880	8882	8884	8886	8888	8890	8892
.949	8892	8894	8896	8898	8900	8902	8904	8906	8908	8910	8913

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	10
.950	8913	8915	8917	8919	8921	8923	8925	8927	8929	8931	8933
.951	8933	8935	8937	8939	8941	8943	8945	8947	8950	8952	8954
.952	8954	8956	8958	8960	8962	8964	8966	8968	8970	8972	8974
.953	8974	8976	8978	8980	8983	8985	8987	8989	8991	8993	8995
.954	8995	8997	8999	9001	9003	9005	9007	9009	9012	9014	9016
.955	9016	9018	9020	9022	9024	9026	9028	9030	9032	9034	9036
.956	9036	9039	9041	9043	9045	9047	9049	9051	9053	9055	9057
.957	9057	9059	9061	9064	9066	9068	9070	9072	9074	9076	9078
.958	9078	9080	9082	9084	9087	9089	9091	9093	9095	9097	9099
.959	9099	9101	9103	9105	9108	9110	9112	9114	9116	9118	9120
.960	9120	9122	9124	9126	9129	9131	9133	9135	9137	9139	9141
.961	9141	9143	9145	9147	9150	9152	9154	9156	9158	9160	9162
.962	9162	9164	9166	9169	9171	9173	9175	9177	9179	9181	9183
.963	9183	9185	9188	9190	9192	9194	9196	9198	9200	9202	9204
.964	9204	9207	9209	9211	9213	9215	9217	9219	9221	9224	9226
.965	9226	9228	9230	9232	9234	9236	9238	9241	9243	9245	9247
.966	9247	9249	9251	9253	9256	9258	9260	9262	9264	9266	9268
.967	9268	9270	9273	9275	9277	9279	9281	9283	9285	9288	9290
.968	9290	9292	9294	9296	9298	9300	9303	9305	9307	9309	9311
.969	9311	9313	9315	9318	9320	9322	9324	9326	9328	9330	9333
.970	9333	9335	9337	9339	9341	9343	9345	9348	9350	9352	9354
.971	9354	9356	9358	9361	9363	9365	9367	9369	9371	9373	9376
.972	9376	9378	9380	9382	9384	9386	9389	9391	9393	9395	9397
.973	9397	9399	9402	9404	9406	9408	9410	9412	9415	9417	9419
.974	9419	9421	9423	9425	9428	9430	9432	9434	9436	9438	9441
.975	9441	9443	9445	9447	9449	9451	9454	9456	9458	9460	9462
.976	9462	9465	9467	9469	9471	9473	9475	9478	9480	9482	9484
.977	9484	9486	9489	9491	9493	9495	9497	9499	9502	9504	9506
.978	9506	9508	9510	9513	9515	9517	9519	9521	9524	9526	9528
.979	9528	9530	9532	9535	9537	9539	9541	9543	9546	9548	9550
980	9550	9552	9554	9557	9559	9561	9563	9565	9568	9570	9572
.981	9572	9574	9576	9579	9581	9583	9585	9587	9590	9592	9594
.982	9594	9596	9598	9601	9603	9605	9607	9609	9612	9614	9616
.983	9616	9618	9621	9623	9625	9627	9629	9632	9634	9636	9638
.984	9638	9641	9643	9645	9647	9649	9652	9654	9656	9658	9661
.985	9661	9663	9665	9667	9669	9672	9674	9676	9678	9681	9683
.986	9683	9685	9687	9689	9692	9694	9696	9698	9701	9703	9705
.987	9705	9707	9710	9712	9714	9716	9719	9721	9723	9725	9727
.988	9727	9730	9732	9734	9736	9739	9741	9743	9745	9748	9750
.989	9750	9752	9754	9757	9759	9761	9763	9766	9768	9770	9772
.990	9772	9775	9777	9779	9781	9784	9786	9788	9790	9793	9795
.991	9795	9797	9799	9802	9804	9806	9808	9811	9813	9815	9817
.992	9817	9820	9822	9824	9827	9829	9831	9833	9836	9838	9840
.993	9840	9842	9845	9847	9849	9851	9854	9856	9858	9861	9863
.994	9863	9865	9867	9870	9872	9874	9876	9879	9881	9883	9886
.995	9886	9888	9890	9892	9895	9897	9899	9901	9904	9906	9908
.996	9908	9911	9913	9915	9917	9920	9922	9924	9927	9929	9931
.997	9931	9933	9936	9938	9940	9943	9945	9947	9949	9952	9954
.998	9954	9956	9959	9961	9963	9966	9968	9970	9972	9975	9977
.999	9977	9979	9982	9984	9986	9988	9991	9993	9995	9998	0000

Table 14

CIRCULAR (TRIGONOMETRIC) FUNCTIONS

(Taken from B. O. Peirce's "Short Table of Integrals," Ginn & Co.)

Radians.	Degrees.	Sines. Nat.	Sines. Log.	Cosines. Nat.	Cosines. Log.	Tangents. Nat.	Tangents. Log.	Cotangents. Nat.	Cotangents. Log.		
0.0000	0°00′	.0000	∞	1.0000	0.0000	.0000	∞	∞	∞	90°00′	1.5708
0.0029	10	.0029	7.4637	1.0000	.0000	.0029	7.4637	343.77	2.5363	50	1.5679
0.0058	20	.0058	.7648	1.0000	.0000	.0058	.7648	171.89	.2352	40	1.5650
0.0087	30	.0087	.9408	1.0000	.0000	.0087	.9409	114.59	.0591	30	1.5621
0.0116	40	.0116	8.0658	.9999	.0000	.0116	8.0658	85.940	1.9342	20	1.5592
0.0145	50	.0145	.1627	.9999	.0000	.0145	.1627	68.750	.8373	10	1.5563
0.0175	1°00′	.0175	8.2419	.9998	9.9999	.0175	8.2419	57.290	1.7581	89°00′	1.5533
0.0204	10	.0204	.3088	.9998	.9999	.0204	.3089	49.104	.6911	50	1.5504
0.0233	20	.0233	.3668	.9997	.9999	.0233	.3669	42.964	.6331	40	1.5475
0.0262	30	.0262	.4179	.9997	.9999	.0262	.4181	38.188	.5819	30	1.5446
0.0291	40	.0291	.4637	.9996	.9998	.0291	.4638	34.368	.5362	20	1.5417
0.0320	50	.0320	.5050	.9995	.9998	.0320	.5053	31.242	.4947	10	1.5388
0.0349	2°00′	.0349	8.5428	.9994	9.9997	.0349	8.5431	28.636	1.4569	88°00′	1.5359
0.0378	10	.0378	.5776	.9993	.9997	.0378	.5779	26.432	.4221	50	1.5330
0.0407	20	.0407	.6097	.9992	.9996	.0407	.6101	24.542	.3899	40	1.5301
0.0436	30	.0436	.6397	.9990	.9996	.0437	.6401	22.904	.3599	30	1.5272
0.0465	40	.0465	.6677	.9989	.9995	.0466	.6682	21.470	.3318	20	1.5243
0.0495	50	.0494	.6940	.9988	.9995	.0495	.6945	20.206	.3055	10	1.5213
0.0524	3°00′	.0523	8.7188	.9986	9.9994	.0524	8.7194	19.081	1.2806	87°00′	1.5184
0.0553	10	.0552	.7423	.9985	.9993	.0553	.7429	18.075	.2571	50	1.5155
0.0582	20	.0581	.7645	.9983	.9993	.0582	.7652	17.169	.2348	40	1.5126
0.0611	30	.0610	.7857	.9981	.9992	.0612	.7865	16.350	.2135	30	1.5097
0.0640	40	.0640	.8059	.9980	.9991	.0641	.8067	15.605	.1933	20	1.5068
0.0669	50	.0669	.8251	.9978	.9990	.0670	.8261	14.924	.1739	10	1.5039
0.0698	4°00′	.0698	8.8436	.9976	9.9989	.0699	8.8446	14.301	1.1554	86°00′	1.5010
0.0727	10	.0727	.8613	.9974	.9989	.0729	.8624	13.727	.1376	50	1.4981
0.0756	20	.0756	.8783	.9971	.9988	.0758	.8795	13.197	.1205	40	1.4952
0.0785	30	.0785	.8946	.9969	.9987	.0787	.8960	12.706	.1040	30	1.4923
0.0814	40	.0814	.9104	.9967	.9986	.0816	.9118	12.251	.0882	20	1.4893
0.0844	50	.0843	.9256	.9964	.9985	.0846	.9272	11.826	.0728	10	1.4864
0.0873	5°00′	.0872	8.9403	.9962	9.9983	.0875	8.9420	11.430	1.0580	85°00′	1.4835
0.0902	10	.0901	.9545	.9959	.9982	.0904	.9563	11.059	.0437	50	1.4806
0.0931	20	.0929	.9682	.9957	.9981	.0934	.9701	10.712	.0299	40	1.4777
0.0960	30	.0958	.9816	.9954	.9980	.0963	.9836	10.385	.0164	30	1.4748
0.0989	40	.0987	.9945	.9951	.9979	.0992	.9966	10.078	.0034	20	1.4719
0.1018	50	.1016	9.0070	.9948	.9977	.1022	9.0093	9.7882	0.9907	10	1.4690
0.1047	6°00	.1045	9.0192	.9945	9.9976	.1051	9.0216	9.5144	0.9784	84°00′	1.4661
0.1076	10	.1074	.0311	.9942	.9975	.1080	.0336	9.2553	.9664	50	1.4632
0.1105	20	.1103	.0426	.9939	.9973	.1110	.0453	9.0098	.9547	40	1.4603
0.1134	30	.1132	.0539	.9936	.9972	.1139	.0567	8.7769	.9433	30	1.4574
0.1164	40	.1161	.0648	.9932	.9971	.1169	.0678	8.5555	.9322	20	1.4544
0.1193	50	.1190	.0755	.9929	.9969	.1198	.0786	8.3450	.9214	10	1.4515
0.1222	7°00′	.1219	9.0859	.9925	9.9968	.1228	9.0891	8.1443	0.9109	83°00′	1.4486
0.1251	10	.1248	.0961	.9922	.9966	.1257	.0995	7.9530	.9005	50	1.4457
0.1280	20	.1276	.1060	.9918	.9964	.1287	.1096	7.7704	.8904	40	1.4428
0.1309	30	.1305	.1157	.9914	.9963	.1317	.1194	7.5958	.8806	30	1.4399
0.1338	40	.1334	.1252	.9911	.9961	.1346	.1291	7.4287	.8709	20	1.4370
0.1367	50	.1363	.1345	.9907	.9959	.1376	.1385	7.2687	.8615	10	1.4341
0.1396	8°00′	.1392	9.1436	.9903	9.9958	.1405	9.1478	7.1154	0.8522	82°00′	1.4312
0.1425	10	.1421	.1525	.9899	.9956	.1435	.1569	6.9682	.8431	50	1.4283
0.1454	20	.1449	.1612	.9894	.9954	.1465	.1658	6.8269	.8342	40	1.4254
0.1484	30	.1478	.1697	.9890	.9952	.1495	.1745	6.6912	.8255	30	1.4224
0.1513	40	.1507	.1781	.9886	.9950	.1524	.1831	6.5606	.8169	20	1.4195
0.1542	50	.1536	.1863	.9881	.9948	.1554	.1915	6.4348	.8085	10	1.4166
0.1571	9°00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81°00′	1.4137
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
		Cosines.		Sines.		Cotangents.		Tangents.		Degrees.	Radians.

CIRCULAR (TRIGONOMETRIC) FUNCTIONS

RADIANS.	DEGREES.	SINES.		COSINES.		TANGENTS.		COTANGENTS.			
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
0.1571	9°00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81°00′	1.4137
0.1600	10	.1593	.2022	.9872	.9944	.1614	.2078	6.1970	.7922	50	1.4108
0.1629	20	.1622	.2100	.9868	.9942	.1644	.2158	6.0844	.7842	40	1.4079
0.1658	30	.1650	.2176	.9863	.9940	.1673	.2236	5.9758	.7764	30	1.4050
0.1687	40	.1679	.2251	.9858	.9938	.1703	.2313	5.8708	.7687	20	1.4021
0.1716	50	.1708	.2324	.9853	.9936	.1733	.2389	5.7694	.7611	10	1.3992
0.1745	10°00′	.1736	9.2397	.9848	9.9934	.1763	9.2463	5.6713	0.7537	80°00′	1.3963
0.1774	10	.1765	.2468	.9843	.9931	.1793	.2536	5.5764	.7464	50	1.3934
0.1804	20	.1794	.2538	.9838	.9929	.1823	.2609	5.4845	.7391	40	1.3904
0.1833	30	.1822	.2606	.9833	.9927	.1853	.2680	5.3955	.7320	30	1.3875
0.1862	40	.1851	.2674	.9827	.9924	.1883	.2750	5.3093	.7250	20	1.3846
0.1891	50	.1880	.2740	.9822	.9922	.1914	.2819	5.2257	.7181	10	1.3817
0.1920	11°00′	.1908	9.2806	.9816	9.9919	.1944	9.2887	5.1446	0.7113	79°00′	1.3788
0.1949	10	.1937	.2870	.9811	.9917	.1974	.2953	5.0658	.7047	50	1.3759
0.1978	20	.1965	.2934	.9805	.9914	.2004	.3020	4.9894	.6980	40	1.3730
0.2007	30	.1994	.2997	.9799	.9912	.2035	.3085	4.9152	.6915	30	1.3701
0.2036	40	.2022	.3058	.9793	.9909	.2065	.3149	4.8430	.6851	20	1.3672
0.2065	50	.2051	.3119	.9787	.9907	.2095	.3212	4.7729	.6788	10	1.3643
0.2094	12°00′	.2079	9.3179	.9781	9.9904	.2126	9.3275	4.7046	0.6725	78°00′	1.3614
0.2123	10	.2108	.3238	.9775	.9901	.2156	.3336	4.6382	.6664	50	1.3584
0.2153	20	.2136	.3296	.9769	.9899	.2186	.3397	4.5736	.6603	40	1.3555
0.2182	30	.2164	.3353	.9763	.9896	.2217	.3458	4.5107	.6542	30	1.3526
0.2211	40	.2193	.3410	.9757	.9893	.2247	.3517	4.4494	.6483	20	1.3497
0.2240	50	.2221	.3466	.9750	.9890	.2278	.3576	4.3897	.6424	10	1.3468
0.2269	13°00′	.2250	9.3521	.9744	9.9887	.2309	9.3634	4.3315	0.6366	77°00′	1.3439
0.2298	10	.2278	.3575	.9737	.9884	.2339	.3691	4.2747	.6309	50	1.3410
0.2327	20	.2306	.3629	.9730	.9881	.2370	.3748	4.2193	.6252	40	1.3381
0.2356	30	.2334	.3682	.9724	.9878	.2401	.3804	4.1653	.6196	30	1.3352
0.2385	40	.2363	.3734	.9717	.9875	.2432	.3859	4.1126	.6141	20	1.3323
0.2414	50	.2391	.3786	.9710	.9872	.2462	.3914	4.0611	.6086	10	1.3294
0.2443	14°00′	.2419	9.3837	.9703	9.9869	.2493	9.3968	4.0108	0.6032	76°00′	1.3265
0.2473	10	.2447	.3887	.9696	.9866	.2524	.4021	3.9617	.5979	50	1.3235
0.2502	20	.2476	.3937	.9689	.9863	.2555	.4074	3.9136	.5926	40	1.3206
0.2531	30	.2504	.3986	.9681	.9859	.2586	.4127	3.8667	.5873	30	1.3177
0.2560	40	.2532	.4035	.9674	.9856	.2617	.4178	3.8208	.5822	20	1.3148
0.2589	50	.2560	.4083	.9667	.9853	.2648	.4230	3.7760	.5770	10	1.3119
0.2618	15°00′	.2588	9.4130	.9659	9.9849	.2679	9.4281	3.7321	0.5719	75°00′	1.3090
0.2647	10	.2616	.4177	.9652	.9846	.2711	.4331	3.6891	.5669	50	1.3061
0.2676	20	.2644	.4223	.9644	.9843	.2742	.4381	3.6470	.5619	40	1.3032
0.2705	30	.2672	.4269	.9636	.9839	.2773	.4430	3.6059	.5570	30	1.3003
0.2734	40	.2700	.4314	.9628	.9836	.2805	.4479	3.5656	.5521	20	1.2974
0.2763	50	.2728	.4359	.9621	.9832	.2836	.4527	3.5261	.5473	10	1.2945
0.2793	16°00′	.2756	9.4403	.9613	9.9828	.2867	9.4575	3.4874	0.5425	74°00′	1.2915
0.2822	10	.2784	.4447	.9605	.9825	.2899	.4622	3.4495	.5378	50	1.2886
0.2851	20	.2812	.4491	.9596	.9821	.2931	.4669	3.4124	.5331	40	1.2857
0.2880	30	.2840	.4533	.9588	.9817	.2962	.4716	3.3759	.5284	30	1.2828
0.2909	40	.2868	.4576	.9580	.9814	.2994	.4762	3.3402	.5238	20	1.2799
0.2938	50	.2896	.4618	.9572	.9810	.3026	.4808	3.3052	.5192	10	1.2770
0.2967	17°00′	.2924	9.4659	.9563	9.9806	.3057	9.4853	3.2709	0.5147	73°00′	1.2741
0.2996	10	.2952	.4700	.9555	.9802	.3089	.4898	3.2371	.5102	50	1.2712
0.3025	20	.2979	.4741	.9546	.9798	.3121	.4943	3.2041	.5057	40	1.2683
0.3054	30	.3007	.4781	.9537	.9794	.3153	.4987	3.1716	.5013	30	1.2654
0.3083	40	.3035	.4821	.9528	.9790	.3185	.5031	3.1397	.4969	20	1.2625
0.3113	50	.3062	.4861	.9520	.9786	.3217	.5075	3.1084	.4925	10	1.2595
0.3142	18°00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72°00′	1.2566
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
		COSINES.		SINES.		COTANGENTS.		TANGENTS.		DEGREES.	RADIANS.

Table 14 (*continued*)

CIRCULAR (TRIGONOMETRIC) FUNCTIONS

RADIANS.	DEGREES.	SINES. Nat.	SINES. Log.	COSINES Nat.	COSINES Log.	TANGENTS. Nat.	TANGENTS. Log.	COTANGENTS. Nat.	COTANGENTS. Log.		
0.3142	18°00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72°00′	1.2566
0.3171	10	.3118	.4939	.9502	.9778	.3281	.5161	3.0475	.4839	50	1.2537
0.3200	20	.3145	.4977	.9492	.9774	.3314	.5203	3.0178	.4797	40	1.2508
0.3229	30	.3173	.5015	.9483	.9770	.3346	.5245	2.9887	.4755	30	1.2479
0.3258	40	.3201	.5052	.9474	.9765	.3378	.5287	2.9600	.4713	20	1.2450
0.3287	50	.3228	.5090	.9465	.9761	.3411	.5329	2.9319	.4671	10	1.2421
0.3316	19°00′	.3256	9.5126	.9455	9.9757	.3443	9.5370	2.9042	0.4630	71°00′	1.2392
0.3345	10	.3283	.5163	.9446	.9752	.3476	.5411	2.8770	.4589	50	1.2363
0.3374	20	.3311	.5199	.9436	.9748	.3508	.5451	2.8502	.4549	40	1.2334
0.3403	30	.3338	.5235	.9426	.9743	.3541	.5491	2.8239	.4509	30	1.2305
0.3432	40	.3365	.5270	.9417	.9739	.3574	.5531	2.7980	.4469	20	1.2275
0.3462	50	.3393	.5306	.9407	.9734	.3607	.5571	2.7725	.4429	10	1.2246
0.3491	20°00′	.3420	9.5341	.9397	9.9730	.3640	9.5611	2.7475	0.4389	70°00′	1.2217
0.3520	10	.3448	.5375	.9387	.9725	.3673	.5650	2.7228	.4350	50	1.2188
0.3549	20	.3475	.5409	.9377	.9721	.3706	.5689	2.6985	.4311	40	1.2159
0.3578	30	.3502	.5443	.9367	.9716	.3739	.5727	2.6746	.4273	30	1.2130
0.3607	40	.3529	.5477	.9356	.9711	.3772	.5766	2.6511	.4234	20	1.2101
0.3636	50	.3557	.5510	.9346	.9706	.3805	.5804	2.6279	.4196	10	1.2072
0.3665	21°00′	.3584	9.5543	.9336	9.9702	.3839	9.5842	2.6051	0.4158	69°00′	1.2043
0.3694	10	.3611	.5576	.9325	.9697	.3872	.5879	2.5826	.4121	50	1.2014
0.3723	20	.3638	.5609	.9315	.9692	.3906	.5917	2.5605	.4083	40	1.1985
0.3752	30	.3665	.5641	.9304	.9687	.3939	.5954	2.5386	.4046	30	1.1956
0.3782	40	.3692	.5673	.9293	.9682	.3973	.5991	2.5172	.4009	20	1.1926
0.3811	50	.3719	.5704	.9283	.9677	.4006	.6028	2.4960	.3972	10	1.1897
0.3840	22°00′	.3746	9.5736	.9272	9.9672	.4040	9.6064	2.4751	0.3936	68°00′	1.1868
0.3869	10	.3773	.5767	.9261	.9667	.4074	.6100	2.4545	.3900	50	1.1839
0.3898	20	.3800	.5798	.9250	.9661	.4108	.6136	2.4342	.3864	40	1.1810
0.3927	30	.3827	.5828	.9239	.9656	.4142	.6172	2.4142	.3828	30	1.1781
0.3956	40	.3854	.5859	.9228	.9651	.4176	.6208	2.3945	.3792	20	1.1752
0.3985	50	.3881	.5889	.9216	.9646	.4210	.6243	2.3750	.3757	10	1.1723
0.4014	23°00′	.3907	9.5919	.9205	9.9640	.4245	9.6279	2.3559	0.3721	67°00′	1.1694
0.4043	10	.3934	.5948	.9194	.9635	.4279	.6314	2.3369	.3686	50	1.1665
0.4072	20	.3961	.5978	.9182	.9629	.4314	.6348	2.3183	.3652	40	1.1636
0.4102	30	.3987	.6007	.9171	.9624	.4348	.6383	2.2998	.3617	30	1.1606
0.4131	40	.4014	.6036	.9159	.9618	.4383	.6417	2.2817	.3583	20	1.1577
0.4160	50	.4041	.6065	.9147	.9613	.4417	.6452	2.2637	.3548	10	1.1548
0.4189	24°00′	.4067	9.6093	.9135	9.9607	.4452	9.6486	2.2460	0.3514	66°00′	1.1519
0.4218	10	.4094	.6121	.9124	.9602	.4487	.6520	2.2286	.3480	50	1.1490
0.4247	20	.4120	.6149	.9112	.9596	.4522	.6553	2.2113	.3447	40	1.1461
0.4276	30	.4147	.6177	.9100	.9590	.4557	.6587	2.1943	.3413	30	1.1432
0.4305	40	.4173	.6205	.9088	.9584	.4592	.6620	2.1775	.3380	20	1.1403
0.4334	50	.4200	.6232	.9075	.9579	.4628	.6654	2.1609	.3346	10	1.1374
0.4363	25°00′	.4226	9.6259	.9063	9.9573	.4663	9.6687	2.1445	0.3313	65°00′	1.1345
0.4392	10	.4253	.6286	.9051	.9567	.4699	.6720	2.1283	.3280	50	1.1316
0.4422	20	.4279	.6313	.9038	.9561	.4734	.6752	2.1123	.3248	40	1.1286
0.4451	30	.4305	.6340	.9026	.9555	.4770	.6785	2.0965	.3215	30	1.1257
0.4480	40	.4331	.6366	.9013	.9549	.4806	.6817	2.0809	.3183	20	1.1228
0.4509	50	.4358	.6392	.9001	.9543	.4841	.6850	2.0655	.3150	10	1.1199
0.4538	26°00′	.4384	9.6418	.8988	9.9537	.4877	9.6882	2.0503	0.3118	64°00′	1.1170
0.4567	10	.4410	.6444	.8975	.9530	.4913	.6914	2.0353	.3086	50	1.1141
0.4596	20	.4436	.6470	.8962	.9524	.4950	.6946	2.0204	.3054	40	1.1112
0.4625	30	.4462	.6495	.8949	.9518	.4986	.6977	2.0057	.3023	30	1.1083
0.4654	40	.4488	.6521	.8936	.9512	.5022	.7009	1.9912	.2991	20	1.1054
0.4683	50	.4514	.6546	.8923	.9505	.5059	.7040	1.9768	.2960	10	1.1025
0.4712	27°00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63°00′	1.0996
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
		COSINES.		SINES.		COTANGENTS.		TANGENTS		DEGREES.	RADIANS.

CIRCULAR (TRIGONOMETRIC) FUNCTIONS

RADIANS.	DEGREES.	SINES. Nat.	SINES. Log.	COSINES. Nat.	COSINES. Log.	TANGENTS. Nat.	TANGENTS. Log.	COTANGENTS. Nat.	COTANGENTS. Log.		
0.4712	27°00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63°00′	1.0996
0.4741	10	.4566	.6595	.8897	.9492	.5132	.7103	1.9486	.2897	50	1.0966
0.4771	20	.4592	.6620	.8884	.9486	.5169	.7134	1.9347	.2866	40	1.0937
0.4800	30	.4617	.6644	.8870	.9479	.5206	.7165	1.9210	.2835	30	1.0908
0.4829	40	.4643	.6668	.8857	.9473	.5243	.7196	1.9074	.2804	20	1.0879
0.4858	50	.4669	.6692	.8843	.9466	.5280	.7226	1.8940	.2774	10	1.0850
0.4887	28°00′	.4695	9.6716	.8829	9.9459	.5317	9.7257	1.8807	0.2743	62°00′	1.0821
0.4916	10	.4720	.6740	.8816	.9453	.5354	.7287	1.8676	.2713	50	1.0792
0.4945	20	.4746	.6763	.8802	.9446	.5392	.7317	1.8546	.2683	40	1.0763
0.4974	30	.4772	.6787	.8788	.9439	.5430	.7348	1.8418	.2652	30	1.0734
0.5003	40	.4797	.6810	.8774	.9432	.5467	.7378	1.8291	.2622	20	1.0705
0.5032	50	.4823	.6833	.8760	.9425	.5505	.7408	1.8165	.2592	10	1.0676
0.5061	29°00′	.4848	9.6856	.8746	9.9418	.5543	9.7438	1.8040	0.2562	61°00′	1.0647
0.5091	10	.4874	.6878	.8732	.9411	.5581	.7467	1.7917	.2533	50	1.0617
0.5120	20	.4899	.6901	.8718	.9404	.5619	.7497	1.7796	.2503	40	1.0588
0.5149	30	.4924	.6923	.8704	.9397	.5658	.7526	1.7675	.2474	30	1.0559
0.5178	40	.4950	.6946	.8689	.9390	.5696	.7556	1.7556	.2444	20	1.0530
0.5207	50	.4975	.6968	.8675	.9383	.5735	.7585	1.7437	.2415	10	1.0501
0.5236	30°00′	.5000	9.6990	.8660	9.9375	.5774	9.7614	1.7321	0.2386	60°00′	1.0472
0.5265	10	.5025	.7012	.8646	.9368	.5812	.7644	1.7205	.2356	50	1.0443
0.5294	20	.5050	.7033	.8631	.9361	.5851	.7673	1.7090	.2327	40	1.0414
0.5323	30	.5075	.7055	.8616	.9353	.5890	.7701	1.6977	.2299	30	1.0385
0.5352	40	.5100	.7076	8601	.9346	.5930	.7730	1.6864	.2270	20	1.0356
0.5381	50	.5125	.7097	.8587	.9338	.5969	.7759	1.6753	.2241	10	1.0327
0.5411	31°00′	.5150	9.7118	.8572	9.9331	.6009	9.7788	1.6643	0.2212	59°00′	1.0297
0.5440	10	.5175	.7139	.8557	.9323	.6048	.7816	1.6534	.2184	50	1.0268
0.5469	20	.5200	.7160	.8542	.9315	.6088	.7845	1.6426	.2155	40	1.0239
0.5498	30	.5225	.7181	.8526	.9308	.6128	.7873	1.6319	.2127	30	1.0210
0.5527	40	.5250	.7201	.8511	.9300	.6168	.7902	1.6212	.2098	20	1.0181
0.5556	50	.5275	.7222	.8496	.9292	.6208	.7930	1.6107	.2070	10	1.0152
0.5585	32°00′	.5299	9.7242	.8480	9.9284	.6249	9.7958	1.6003	0.2042	58°00′	1.0123
0.5614	10	.5324	.7262	.8465	.9276	.6289	.7986	1.5900	.2014	50	1.0094
0.5643	20	.5348	.7282	.8450	.9268	.6330	.8014	1.5798	.1986	40	1.0065
0.5672	30	.5373	.7302	.8434	.9260	.6371	.8042	1.5697	.1958	30	1.0036
0.5701	40	.5398	.7322	.8418	.9252	.6412	.8070	1.5597	.1930	20	1.0007
0.5730	50	.5422	.7342	.8403	.9244	.6453	.8097	1.5497	.1903	10	0.9977
0.5760	33°00′	.5446	9.7361	.8387	9.9236	.6494	9.8125	1.5399	0.1875	57°00′	0.9948
0.5789	10	.5471	.7380	.8371	.9228	.6536	.8153	1.5301	1847	50	0.9919
0.5818	20	.5495	.7400	.8355	.9219	.6577	.8180	1.5204	.1820	40	0.9890
0.5847	30	.5519	.7419	.8339	.9211	.6619	.8208	1.5108	.1792	30	0.9861
0.5876	40	.5544	.7438	.8323	.9203	.6661	.8235	1.5013	.1765	20	0.9832
0.5905	50	.5568	.7457	.8307	.9194	.6703	.8263	1.4919	.1737	10	0.9803
0.5934	34°00′	.5592	9.7476	.8290	9.9186	.6745	9.8290	1.4826	0.1710	56°00′	0.9774
0.5963	10	.5616	.7494	.8274	.9177	.6787	.8317	1.4733	.1683	50	0.9745
0.5992	20	.5640	.7513	.8258	.9169	6830	.8344	1.4641	.1656	40	0.9716
0.6021	30	.5664	.7531	.8241	.9160	.6873	.8371	1.4550	.1629	30	0.9687
0.6050	40	.5688	.7550	.8225	.9151	.6916	.8398	1.4460	.1602	20	0.9657
0.6080	50	.5712	.7568	.8208	.9142	.6959	.8425	1.4370	.1575	10	0.9628
0.6109	35°00′	.5736	9.7586	.8192	9.9134	.7002	9.8452	1.4281	0.1548	55°00′	0.9599
0.6138	10	.5760	.7604	.8175	.9125	.7046	.8479	1.4193	.1521	50	0.9570
0.6167	20	.5783	.7622	.8158	.9116	.7089	.8506	1.4106	.1494	40	0.9541
0.6196	30	.5807	.7640	.8141	.9107	.7133	.8533	1.4019	.1467	30	0.9512
0.6225	40	.5831	.7657	.8124	.9098	.7177	.8559	1.3934	.1441	20	0.9483
0.6254	50	.5854	.7675	8107	.9089	7221	.8586	1.3848	.1414	10	0.9454
0.6283	36°00′	.5878	9.7692	8090	9.9080	.7265	9.8613	1.3764	0.1387	54°00′	0.9425
		Nat.	Log.	Nat.	Log	Nat.	Log.	Nat	Log.	DEGREES.	RADIANS.
		COSINES.		SINES.		COTANGENTS.		TANGENTS.			

CIRCULAR (TRIGONOMETRIC) FUNCTIONS

RADIANS.	DEGREES.	SINES.		COSINES.		TANGENTS.		COTANGENTS.			
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
0.6283	36°00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54°00′	0.9425
0.6312	10	.5901	.7710	.8073	.9070	.7310	.8639	1.3680	.1361	50	0.9396
0.6341	20	.5925	.7727	.8056	.9061	.7355	.8666	1.3597	.1334	40	0.9367
0.6370	30	.5948	.7744	.8039	.9052	.7400	.8692	1.3514	.1308	30	0.9338
0.6400	40	.5972	.7761	.8021	.9042	.7445	.8718	1.3432	.1282	20	0.9308
0.6429	50	.5995	.7778	.8004	.9033	.7490	.8745	1.3351	.1255	10	0.9279
0.6458	37°00′	.6018	9.7795	.7986	9.9023	.7536	9.8771	1.3270	0.1229	53°00′	0.9250
0.6487	10	.6041	.7811	.7969	.9014	.7581	.8797	1.3190	.1203	50	0.9221
0.6516	20	.6065	.7828	.7951	.9004	.7627	.8824	1.3111	.1176	40	0.9192
0.6545	30	.6088	.7844	.7934	.8995	.7673	.8850	1.3032	.1150	30	0.9163
0.6574	40	.6111	.7861	.7916	.8985	.7720	.8876	1.2954	.1124	20	0.9134
0.6603	50	.6134	.7877	.7898	.8975	.7766	.8902	1.2876	.1098	10	0.9105
0.6632	38°00′	.6157	9.7893	.7880	9.8965	.7813	9.8928	1.2799	0.1072	52°00′	0.9076
0.6661	10	.6180	.7910	.7862	.8955	.7860	.8954	1.2723	.1046	50	0.9047
0.6690	20	.6202	.7926	.7844	.8945	.7907	.8980	1.2647	.1020	40	0.9018
0.6720	30	.6225	.7941	.7826	.8935	.7954	.9006	1.2572	.0994	30	0.8988
0.6749	40	.6248	.7957	.7808	.8925	.8002	.9032	1.2497	.0968	20	0.8959
0.6778	50	.6271	.7973	.7790	.8915	.8050	.9058	1.2423	.0942	10	0.8930
0.6807	39°00′	.6293	9.7989	.7771	9.8905	.8098	9.9084	1.2349	0.0916	51°00′	0.8901
0.6836	10	.6316	.8004	.7753	.8895	.8146	.9110	1.2276	.0890	50	0.8872
0.6865	20	.6338	.8020	.7735	.8884	.8195	.9135	1.2203	.0865	40	0.8843
0.6894	30	.6361	.8035	.7716	.8874	.8243	.9161	1.2131	.0839	30	0.8814
0.6923	40	.6383	.8050	.7698	.8864	.8292	.9187	1.2059	.0813	20	0.8785
0.6952	50	.6406	.8066	.7679	.8853	.8342	.9212	1.1988	.0788	10	0.8756
0.6981	40°00′	.6428	9.8081	.7660	9.8843	.8391	9.9238	1.1918	0.0762	50°00′	0.8727
0.7010	10	.6450	.8096	.7642	.8832	.8441	.9264	1.1847	.0736	50	0.8698
0.7039	20	.6472	.8111	.7623	.8821	.8491	.9289	1.1778	.0711	40	0.8668
0.7069	30	.6494	.8125	.7604	.8810	.8541	.9315	1.1708	.0685	30	0.8639
0.7098	40	.6517	.8140	.7585	.8800	.8591	.9341	1.1640	.0659	20	0.8610
0.7127	50	.6539	.8155	.7566	.8789	.8642	.9366	1.1571	.0634	10	0.8581
0.7156	41°00′	.6561	9.8169	.7547	9.8778	.8693	9.9392	1.1504	0.0608	49°00′	0.8552
0.7185	10	.6583	.8184	.7528	.8767	.8744	.9417	1.1436	.0583	50	0.8523
0.7214	20	.6604	.8198	.7509	.8756	.8796	.9443	1.1369	.0557	40	0.8494
0.7243	30	.6626	.8213	.7490	.8745	.8847	.9468	1.1303	.0532	30	0.8465
0.7272	40	.6648	.8227	.7470	.8733	.8899	.9494	1.1237	.0506	20	0.8436
0.7301	50	.6670	.8241	.7451	.8722	.8952	.9519	1.1171	.0481	10	0.8407
0.7330	42°00′	.6691	9.8255	.7431	9.8711	.9004	9.9544	1.1106	0.0456	48°00′	0.8378
0.7359	10	.6713	.8269	.7412	.8699	.9057	.9570	1.1041	.0430	50	0.8348
0.7389	20	.6734	.8283	.7392	.8688	.9110	.9595	1.0977	.0405	40	0.8319
0.7418	30	.6756	.8297	.7373	.8676	.9163	.9621	1.0913	.0379	30	0.8290
0.7447	40	.6777	.8311	.7353	.8665	.9217	.9646	1.0850	.0354	20	0.8261
0.7476	50	.6799	.8324	.7333	.8653	.9271	.9671	1.0786	.0329	10	0.8232
0.7505	43°00′	.6820	9.8338	.7314	9.8641	.9325	9.9697	1.0724	0.0303	47°00′	0.8203
0.7534	10	.6841	.8351	.7294	.8629	.9380	.9722	1.0661	.0278	50	0.8174
0.7563	20	.6862	.8365	.7274	.8618	.9435	.9747	1.0599	.0253	40	0.8145
0.7592	30	.6884	.8378	.7254	.8606	.9490	.9772	1.0538	.0228	30	0.8116
0.7621	40	.6905	.8391	.7234	.8594	.9545	.9798	1.0477	.0202	20	0.8087
0.7650	50	.6926	.8405	.7214	.8582	.9601	.9823	1.0416	.0177	10	0.8058
0.7679	44°00′	.6947	9.8418	.7193	9.8569	.9657	9.9848	1.0355	0.0152	46°00′	0.8029
0.7709	10	.6967	.8431	.7173	.8557	.9713	.9874	1.0295	.0126	50	0.7999
0.7738	20	.6988	.8444	.7153	.8545	.9770	.9899	1.0235	.0101	40	0.7970
0.7767	30	.7009	.8457	.7133	.8532	.9827	.9924	1.0176	.0076	30	0.7941
0.7796	40	.7030	.8469	.7112	.8520	.9884	.9949	1.0117	.0051	20	0.7912
0.7825	50	.7050	.8482	.7092	.8507	.9942	.9975	1.0058	.0025	10	0.7883
0.7854	45°00′	.7071	9.8495	.7071	9.8495	1.0000	0.0000	1.0000	0.0000	45°00′	0.7854
		Nat.	Log.	Nat	Log.	Nat.	Log	Nat.	Log.		
		COSINES.		SINES.		COTANGENTS.		TANGENTS.		DEGREES.	RADIANS.

TABLE 15

CIRCULAR (TRIGONOMETRIC) FUNCTIONS

RADIANS.	SINES. Nat.	SINES. Log.	COSINES. Nat.	COSINES. Log.	TANGENTS. Nat.	TANGENTS. Log.	COTANGENTS. Nat.	COTANGENTS. Log.	DEGREES.
0.00	0.00000	— ∞	1.00000	0.00000	— ∞	— ∞	∞	∞	00°00′
.01	.01000	7.99999	0.99995	9.99998	0.01000	8.00001	99.997	1.99999	00 34
.02	.02000	8.30100	.99980	.99991	.02000	.30109	49.993	.69891	01 09
.03	.03000	.47706	.99955	.99980	.03001	.47725	33.323	.52275	01 43
.04	.03999	.60194	.99920	.99965	.04002	.60229	24.987	.39771	02 18
0.05	0.04998	8.69879	0.99875	9.99946	0.05004	8.69933	19.983	1.30067	02°52′
.06	.05996	.77789	.99820	.99922	.06007	.77867	16.647	.22133	03 26
.07	.06994	.84474	.99755	.99894	.07011	.84581	14.262	.15419	04 01
.08	.07991	.90263	.99680	.99861	.08017	.90402	12.473	.09598	04 35
.09	.08988	.95366	.99595	.99824	.09024	.95542	11.081	.04458	05 09
0.10	0.09983	8.99928	0.99500	9.99782	0.10033	9.00145	9.9666	0.99855	05°44′
.11	.10978	9.04052	.99396	.99737	.11045	.04315	9.0542	.95685	06 18
.12	.11971	.07814	.99281	.99687	.12058	.08127	8.2933	.91873	06 53
.13	.12963	.11272	.99156	.99632	.13074	.11640	7.6489	.88360	07 27
.14	.13954	.14471	.99022	.99573	.14092	.14898	7.0961	.85102	08 01
0.15	0.14944	9.17446	0.98877	9.99510	0.15114	9.17937	6.6166	0.82063	08°36′
.16	.15932	.20227	.98723	.99442	.16138	.20785	6.1966	.79215	09 10
.17	.16918	.22836	.98558	.99369	.17166	.23466	5.8256	.76534	09 44
.18	.17903	.25292	.98384	.99293	.18197	.26000	5.4954	.74000	10 19
.19	.18886	.27614	.98200	.99211	.19232	.28402	5.1997	.71598	10 53
0.20	0.19867	9.29813	0.98007	9.99126	0.20271	9.30688	4.9332	0.69312	11°28′
.21	20846	.31902	.97803	.99035	.21314	.32867	4.6917	.67133	12 02
.22	.21823	.33891	.97590	.98940	.22362	.34951	4.4719	.65049	12 36
.23	.22798	.35789	.97367	.98841	.23414	.36948	4.2709	.63052	13 11
.24	.23770	.37603	.97134	.98737	.24472	.38866	4.0864	.61134	13 45
0.25	0.24740	9.39341	0.96891	9.98628	0.25534	9.40712	3.9163	0.59288	14°19′
.26	.25708	.41007	.96639	.98515	.26602	.42491	3.7592	.57509	14 54
.27	.26673	.42607	.96377	.98397	.27676	.44210	3.6133	.55790	15 28
.28	.27636	.44147	.96106	.98275	.28755	.45872	3.4776	.54128	16 03
.29	.28595	.45629	.95824	.98148	.29841	.47482	3.3511	.52518	16 37
0.30	0.29552	9.47059	0.95534	9.98016	0.30934	9.49043	3.2327	0.50957	17°11′
.31	.30506	.48438	.95233	.97879	.32033	.50559	3.1218	.49441	17 46
.32	.31457	.49771	.94924	.97737	.33139	.52034	3.0176	.47966	18 20
.33	.32404	.51060	.94604	.97591	.34252	.53469	2.9195	.46531	18 54
.34	.33349	.52308	.94275	.97440	.35374	.54868	2.8270	.45132	19 29
0.35	0.34290	9.53516	0.93937	9.97284	0.36503	9.56233	2.7395	0.43767	20°03′
.36	.35227	.54688	.93590	.97123	.37640	.57565	2.6567	.42435	20 38
.37	.36162	.55825	.93233	.96957	.38786	.58868	2.5782	.41132	21 12
.38	.37092	.56928	.92866	.96786	.39941	.60142	2.5037	.39858	21 46
.39	.38019	.58000	.92491	.96610	.41105	.61390	2.4328	.38610	22 21
0.40	0.38942	9.59042	0.92106	9.96429	0.42279	9.62613	2.3652	0.37387	22°55′
.41	.39861	.60055	.91712	.96243	.43463	.63812	2.3008	.36188	23 29
.42	.40776	.61041	.91309	.96051	.44657	.64989	2.2393	.35011	24 04
.43	.41687	.62000	.90897	.95855	.45862	.66145	2.1804	.33855	24 38
.44	.42594	.62935	.90475	.95653	.47078	.67282	2.1241	.32718	25 13
0.45	0.43497	9.63845	0.90045	9.95446	0.48306	9.68400	2.0702	0.31600	25°47′
.46	.44395	.64733	.89605	.95233	.49545	.69500	2.0184	.30500	26 21
.47	.45289	.65599	.89157	.95015	.50797	.70583	1.9686	.29417	26 56
.48	.46178	.66443	.88699	.94792	.52061	.71651	1.9208	.28349	27 30
.49	.47063	.67268	.88233	.94563	.53339	.72704	1.8748	.27296	28 04
0 50	0.47943	9.68072	0.87758	9.94329	0.54630	9.73743	1.8305	0.26257	28°39′

CIRCULAR (TRIGONOMETRIC) FUNCTIONS

RADIANS.	SINES.		COSINES.		TANGENTS		COTANGENTS.		DEGREES.
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
0.50	0.47943	9.68072	0.87758	9.94329	0.54630	9.73743	1.8305	0.26257	28°39′
.51	.48818	.68858	.87274	.94089	.55936	.74769	.7878	.25231	29 13
.52	.49688	.69625	.86782	.93843	.57256	.75782	.7465	.24218	29 48
.53	.50553	.70375	.86281	.93591	.58592	.76784	.7067	.23216	30 22
.54	.51414	.71108	.85771	.93334	.59943	.77774	.6683	.22226	30 56
0.55	0.52269	9.71824	0.85252	9.93071	0.61311	9.78754	1.6310	0.21246	31°31′
.56	.53119	.72525	.84726	.92801	.62695	.79723	.5950	.20277	32 05
.57	.53963	.73210	.84190	.92526	.64097	.80684	.5601	.19316	32 40
.58	.54802	.73880	.83646	.92245	.65517	.81635	.5263	.18365	33 14
.59	.55636	.74536	.83094	.91957	.66956	.82579	.4935	.17421	33 48
0.60	0.56464	9.75177	0.82534	9.91663	0.68414	9.83514	1.4617	0.16486	34°23′
.61	.57287	.75805	.81965	.91363	.69892	.84443	.4308	.15557	34 57
.62	.58104	.76420	.81388	.91056	.71391	.85364	.4007	.14636	35 31
.63	.58914	.77022	.80803	.90743	.72911	.86280	.3715	.13720	36 06
.64	.59720	.77612	.80210	.90423	.74454	.87189	.3431	.12811	36 40
0.65	0.60519	9.78189	0.79608	9.90096	0.76020	9.88093	1.3154	0.11907	37°15′
.66	.61312	.78754	.78999	.89762	.77610	.88992	.2885	.11008	37 49
.67	.62099	.79308	.78382	.89422	.79225	.89886	.2622	.10114	38 23
.68	.62879	.79851	.77757	.89074	.80866	.90777	.2366	.09223	38 58
.69	.63654	.80382	.77125	.88719	.82534	.91663	.2116	.08337	39 32
0.70	0.64422	9.80903	0.76484	9.88357	0.84229	9.92546	1.1872	0.07454	40°06′
.71	.65183	.81414	.75836	.87988	.85953	.93426	.1634	.06574	40 41
.72	.65938	.81914	.75181	.87611	.87707	.94303	.1402	.05697	41 15
.73	.66687	.82404	.74517	.87226	.89492	.95178	.1174	.04822	41 50
.74	.67429	.82885	.73847	.86833	.91309	.96051	.0952	.03949	42 24
0.75	0.68164	9.83355	0.73169	9.86433	0.93160	9.96923	1.0734	0.03077	42°58′
.76	.68892	.83817	.72484	.86024	.95045	.97793	.0521	.02207	43 33
.77	.69614	.84269	.71791	.85607	.96967	.98662	.0313	.01338	44 07
.78	.70328	.84713	.71091	.85182	.98926	9.99531	1.0109	.00469	44 41
.79	.71035	.85147	.70385	.84748	1.0092	0.00400	0.99084	9.99600	45 16
0.80	0.71736	9.85573	0.69671	9.84305	1.0296	0.01268	0.97121	9.98732	45°50′
.81	.72429	.85991	.68950	.83853	.0505	.02138	.95197	.97862	46 25
.82	.73115	.86400	.68222	.83393	.0717	.03008	.93309	.96992	46 59
.83	.73793	.86802	.67488	.82922	.0934	.03879	.91455	.96121	47 33
.84	.74464	.87195	.66746	.82443	.1156	.04752	.89635	.95248	48 08
0.85	0.75128	9.87580	0.65998	9.81953	1.1383	0.05627	0.87848	9.94373	48°42′
.86	.75784	.87958	.65244	.81454	.1616	.06504	.86091	.93496	49 16
.87	.76433	.88328	.64483	.80944	.1853	.07384	.84365	.92616	49 51
.88	.77074	.88691	.63715	.80424	.2097	.08266	.82668	.91734	50 25
.89	.77707	.89046	.62941	.79894	.2346	.09153	.80998	.90847	51 00
0.90	0.78333	9.89394	0.62161	9.79352	1.2602	0.10043	0.79355	9.89957	51°34′
.91	.78950	.89735	.61375	.78799	.2864	.10937	.77738	.89063	52 08
.92	.79560	.90070	.60582	.78234	.3133	.11835	.76146	.88165	52 43
.93	.80162	.90397	.59783	.77658	.3409	.12739	.74578	.87261	53 17
.94	.80756	.90717	.58979	.77070	.3692	.13648	.73034	.86352	53 51
0.95	0.81342	9.91031	0.58168	9.76469	1.3984	0.14563	0.71511	9.85437	54°26′
.96	.81919	.91339	.57352	.75855	.4284	.15484	.70010	.84516	55 00
.97	.82489	.91639	.56530	.75228	.4592	.16412	.68531	.83588	55 35
.98	.83050	.91934	.55702	.74587	.4910	.17347	.67071	.82653	56 09
.99	.83603	.92222	.54869	.73933	.5237	.18289	.65631	.81711	56 43
1.00	0.84147	9.92504	0.54030	9.73264	1.5574	0.19240	0.64209	9.80760	57°18′

CIRCULAR (TRIGONOMETRIC) FUNCTIONS

RADIANS.	SINES.		COSINES.		TANGENTS.		COTANGENTS.		DEGREES.
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
1.00	0.84147	9.92504	0.54030	9.73264	1.5574	0.19240	0.64209	9.80760	57°18′
.01	.84683	.92780	.53186	.72580	.5922	.20200	.62806	.79800	57 52
.02	.85211	.93049	.52337	.71881	.6281	.21169	.61420	.78831	58 27
.03	.85730	.93313	.51482	.71165	.6652	.22148	.60051	.77852	59 01
.04	.86240	.93571	.50622	.70434	.7036	.23137	.58699	.76863	59 35
1.05	0.86742	9.93823	0.49757	9.69686	1.7433	0.24138	0.57362	9.75862	60°10′
.06	.87236	.94069	.48887	.68920	.7844	.25150	.56040	.74850	60 44
.07	.87720	.94310	.48012	.68135	.8270	.26175	.54734	.73825	61 18
.08	.88196	.94545	.47133	.67332	.8712	.27212	.53441	.72788	61 53
.09	.88663	.94774	.46249	.66510	.9171	.28264	.52162	.71736	62 27
1.10	0.89121	9.94998	0.45360	9.65667	1.9648	0.29331	0.50897	9.70669	63°02′
.11	.89570	.95216	.44466	.64803	2.0143	.30413	.49644	.69587	63 36
.12	.90010	.95429	.43568	.63917	.0660	.31512	.48404	.68488	64 10
.13	.90441	.95637	.42666	.63008	.1198	.32628	.47175	.67372	64 45
.14	.90863	.95839	.41759	.62075	.1759	.33763	.45959	.66237	65 19
1.15	0.91276	9.96036	0.40849	9.61118	2.2345	0.34918	0.44753	9.65082	65°53′
.16	.91680	.96228	.39934	.60134	.2958	.36093	.43558	.63907	66 28
.17	.92075	.96414	.39015	.59123	.3600	.37291	.42373	.62709	67 02
.18	.92461	.96596	.38092	.58084	.4273	.38512	.41199	.61488	67 37
.19	.92837	.96772	.37166	.57015	.4979	.39757	.40034	.60243	68 11
1.20	0.93204	9.96943	0.36236	9.55914	2.5722	0.41030	0.38878	9.58970	68°45′
.21	.93562	.97110	.35302	.54780	.6503	.42330	.37731	.57670	69 20
.22	.93910	.97271	.34365	.53611	.7328	.43660	.36593	.56340	69 54
.23	.94249	.97428	.33424	.52406	.8198	.45022	.35463	.54978	70 28
.24	.94578	.97579	.32480	.51161	.9119	.46418	.34341	.53582	71 03
1.25	0.94898	9.97726	0.31532	9.49875	3.0096	0.47850	0.33227	9.52150	71°37′
.26	.95209	.97868	.30582	.48546	.1133	.49322	.32121	.50678	72 12
.27	.95510	.98005	.29628	.47170	.2236	.50835	.31021	.49165	72 46
.28	.95802	.98137	.28672	.45745	.3413	.52392	.29928	.47608	73 20
.29	.96084	.98265	.27712	.44267	.4672	.53998	.28842	.46002	73 55
1.30	0.96356	9.98388	0.26750	9.42732	3.6021	0.55656	0.27762	9.44344	74°29′
.31	.96618	.98506	.25785	.41137	.7471	.57369	.26687	.42631	75 03
.32	.96872	.98620	.24818	.39476	.9033	.59144	.25619	.40856	75 38
.33	.97115	.98729	.23848	.37744	4.0723	.60984	.24556	.39016	76 12
.34	.97348	.98833	.22875	.35937	.2556	.62896	.23498	.37104	76 47
1.35	0.97572	9.98933	0.21901	9.34046	4.4552	0.64887	0.22446	9.35113	77°21′
.36	.97786	.99028	.20924	.32064	.6734	.66964	.21398	.33036	77 55
.37	.97991	.99119	.19945	.29983	.9131	.69135	.20354	.30865	78 30
.38	.98185	.99205	.18964	.27793	5.1774	.71411	.19315	.28589	79 04
.39	.98370	.99286	.17981	.25482	.4707	.73804	.18279	.26196	79 38
1.40	0.98545	9.99363	0.16997	9.23036	5.7979	0.76327	0.17248	9.23673	80°13′
.41	.98710	.99436	.16010	.20440	6.1654	.78996	.16220	.21004	80 47
.42	.98865	.99504	.15023	.17674	6.5811	.81830	.15195	.18170	81 22
.43	.99010	.99568	.14033	.14716	7.0555	.84853	.14173	.15147	81 56
.44	.99146	.99627	.13042	.11536	7.6018	.88092	.13155	.11908	82 30
1.45	0.99271	9.99682	0.12050	9.08100	8.2381	0.91583	0.12139	9.08417	83°05′
.46	.99387	.99733	.11057	.04364	8.9886	.95369	.11125	.04631	83 39
.47	.99492	.99779	.10063	.00271	9.8874	.99508	.10114	.00492	84 13
.48	.99588	.99821	.09067	8.95747	10.983	1.04074	.09105	8.95926	84 48
.49	.99674	.99858	.08071	.90692	12.350	.09166	.08097	.90834	85 22
1.50	0.99749	9.99891	0.07074	8.84965	14.101	1.14926	0.07091	8.85074	85°57′

CIRCULAR FUNCTIONS AND FACTORIALS

TABLE 15 (*concluded*).—Circular (Trigonometric) Functions

RADIANS.	SINES.		COSINES.		TANGENTS.		COTANGENTS.		DEGREES.
	Nat.	Log	Nat.	Log	Nat.	Log.	Nat.	Log.	
1.50	0.99749	9.99891	0.07074	8.84965	14.101	1.14926	0.07091	8.85074	85°57′
.51	.99815	.99920	.06076	.78361	16.428	.21559	.06087	.78441	86 31
.52	.99871	.99944	.05077	.70565	19.670	.29379	.05084	.70621	87 05
.53	.99917	.99964	.04079	.61050	24.498	.38914	.04082	.61086	87 40
.54	.99953	.99979	.03079	.48843	32.461	.51136	.03081	.48864	88 14
1.55	0.99978	9.99991	0.02079	8.31796	48.078	1.68195	0.02080	8.31805	88°49′
.56	0.99994	9.99997	.01080	8.03327	92.621	1.96671	.01080	8.03329	89 23
.57	1.00000	0.00000	.00080	6.90109	1255.8	3.09891	.00080	6.90109	89 57
.58	0.99996	9.99998	−.00920	7.96396n	108.65	2.03603	−.00920	7.96397n	90 32
.59	0.99982	9.99992	−.01920	8.28336n	52.067	1.71656	−.01921	8.28344n	91 06
1.60	0.99957	9.99981	−0.02920	8.46538n	34.233	1.53444	−0.02921	8.46556n	91°40′

$90° = 1.570\ 7963$ radians.

TABLE 16.—Logarithmic Factorials

Logarithms of the products 1.2.3. ......*n*, *n* from 1 to 100.

See Table 18 for Factorials 1 to 20.

See Table 33 for log. Γ ($n+1$), values of *n* between 1 and 2.

n.	log (*n!*)	*n*.	log (*n!*)	*n*.	log (*n!*)	*n*.	log (*n!*)
1	0.000000	**26**	26.605619	**51**	66.190645	**76**	111.275425
2	0.301030	27	28.036983	52	67.906648	77	113.161916
3	0.778151	28	29.484141	53	69.630924	78	115.054011
4	1.380211	29	30.946539	54	71.363318	79	116.951638
5	2.079181	30	32.423660	55	73.103681	80	118.854728
6	2.857332	**31**	33.915022	**56**	74.851869	**81**	120.763213
7	3.702431	32	35.420172	57	76.607744	82	122.677027
8	4.605521	33	36.938686	58	78.371172	83	124.596105
9	5.559763	34	38.470165	59	80.142024	84	126.520384
10	6.559763	35	40.014233	60	81.920175	85	128.449803
11	7.601156	**36**	41.570535	**61**	83.705505	**86**	130.384301
12	8.680337	37	43.138737	62	85.497896	87	132.323821
13	9.794280	38	44.718520	63	87.297237	88	134.268303
14	10.940408	39	46.309585	64	89.103417	89	136.217693
15	12.116500	40	47.911645	65	90.916330	90	138.171936
16	13.320620	**41**	49.524429	**66**	92.735874	**91**	140.130977
17	14.551069	42	51.147678	67	94.561949	92	142.094765
18	15.806341	43	52.781147	68	96.394458	93	144.063248
19	17.085095	44	54.424599	69	98.233307	94	146.036376
20	18.386125	45	56.077812	70	100.078405	95	148.014099
21	19.708344	**46**	57.740570	**71**	101.929663	**96**	149.996371
22	21.050767	47	59.412668	72	103.786996	97	151.983142
23	22.412494	48	61.093909	73	105.650319	98	153.974368
24	23.792706	49	62.784105	74	107.519550	99	155.970004
25	25.190646	50	64.483075	75	109.394612	100	157.970004

Table 17
HYPERBOLIC FUNCTIONS

u	sinh u		cosh u		tanh u		coth u		gd u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
0.00	0.00000	— ∞	1.00000	0.00000	0.00000	— ∞	∞	∞	00°00′
.01	.01000	8.00001	.00005	.00002	.01000	7.99999	100.003	2.00001	0 34
.02	.02000	.30106	.00020	.00009	.02000	8.30097	50.007	1.69903	1 09
.03	.03000	.47719	.00045	.00020	.02999	.47699	33.343	1.52301	1 43
.04	.04001	.60218	.00080	.00035	.03998	.60183	25.013	1.39817	2 17
0.05	0.05002	8.69915	1.00125	0.00054	0.04996	8.69861	20.017	1.30139	2 52
.06	.06004	.77841	.00180	.00078	.05993	.77763	16.687	.22237	3 26
.07	.07006	.84545	.00245	.00106	.06989	.84439	14.309	.15561	4 00
.08	.08009	.90355	.00320	.00139	.07983	.90216	12.527	.09784	4 35
.09	.09012	.95483	.00405	.00176	.08976	.95307	11.141	.04693	5 09
0.10	0.10017	9.00072	1.00500	0 00217	0.09967	8.99856	10.0333	1.00144	5 43
.11	.11022	.04227	.00606	.00262	.10956	9.03965	9.1275	0.96035	6 17
.12	.12029	.08022	.00721	.00312	.11943	.07710	8.3733	.92290	6 52
.13	.13037	.11517	.00846	.00366	.12927	.11151	7.7356	.88849	7 26
.14	.14046	.14755	.00982	.00424	.13909	.14330	7.1895	.85670	8 00
0.15	0.15056	9.17772	1.01127	0.00487	0.14889	9.17285	6.7166	0.82715	8 34
.16	.16068	.20597	.01283	.00554	.15865	.20044	6.3032	.79956	9 08
.17	.17082	.23254	.01448	.00625	.16838	.22629	5.9389	.77371	9 42
.18	.18097	.25762	.01624	.00700	.17808	.25062	5.6154	.74938	10 15
.19	.19115	.28136	.01810	.00779	.18775	.27357	5 3263	.72643	10 49
0.20	0.20134	9.30392	1.02007	0.00863	0.19738	9.29529	5.0665	0.70471	11 23
.21	.21155	.32541	.02213	.00951	.20697	.31590	4.8317	.68410	11 57
.22	.22178	.34592	.02430	.01043	.21652	.33549	4.6186	.66451	12 30
.23	.23203	.36555	.02657	.01139	.22603	.35416	4.4242	.64584	13 04
.24	.24231	.38437	.02894	.01239	.23550	.37198	4.2464	.62802	13 37
0.25	0.25261	9.40245	1.03141	0.01343	0.24492	9.38902	4.0830	0.61098	14 11
.26	.26294	.41986	.03399	.01452	.25430	.40534	3.9324	.59466	14 44
.27	.27329	.43663	.03667	.01564	.26362	.42099	3.7933	.57901	15 17
.28	.28367	.45282	.03946	.01681	.27291	.43601	3.6643	.56399	15 50
.29	.29408	.46847	.04235	.01801	.28213	.45046	3.5444	.54954	16 23
0.30	0.30452	9.48362	1.04534	0.01926	0.29131	9.46436	3.4327	0.53564	16 56
.31	.31499	.49830	.04844	.02054	.30044	.47775	.3285	.52225	17 29
.32	.32549	.51254	.05164	.02187	.30951	.49067	.2309	.50933	18 02
.33	.33602	.52637	.05495	.02323	.31852	.50314	.1395	.49686	18 34
.34	.34659	.53981	.05836	.02463	.32748	.51518	.0536	.48482	19 07
0.35	0.35719	9.55290	1.06188	0.02607	0.33638	9.52682	2.9729	0.47318	19 39
.36	.36783	.56564	.06550	.02755	.34521	.53809	.8968	.46191	20 12
.37	.37850	.57807	.06923	.02907	.35399	.54899	.8249	.45101	20 44
.38	.38921	.59019	.07307	.03063	.36271	.55956	.7570	.44044	21 16
.39	.39996	.60202	.07702	.03222	.37136	.56980	.6928	.43020	21 48
0.40	0.41075	9.61358	1.08107	0.03385	0.37995	9.57973	2.6319	0.42027	22 20
.41	.42158	.62488	.08523	.03552	.38847	.58936	.5742	.41064	22 52
.42	.43246	.63594	.08950	.03723	.39693	.59871	.5193	.40129	23 23
.43	.44337	.64677	.09388	.03897	.40532	.60780	.4672	.39220	23 55
.44	.45434	.65738	.09837	.04075	.41364	.61663	4175	.38337	24 26
0.45	0.46534	9.66777	1 102970	.04256	0.42190	9.62521	2.3702	0.37479	24 57
.46	.47640	.67797	.10768	.04441	.43008	.63355	.3251	.36645	25 28
.47	.48750	.68797	.11250	.04630	.43820	.64167	.2821	.35833	25 59
.48	.49865	.69779	.11743	.04822	.44624	.64957	.2409	.35043	26 30
.49	.50984	.70744	.12247	.05018	.45422	.65726	.2016	.34274	27 01
0.50	0.52110	9.71692	1.12763	0.05217	0.46212	9.66475	2.1640	0.33525	27 31

TABLE 17 *(continued)*

HYBERBOLIC FUNCTIONS

u	sinh u		cosh u		tanh u		coth u		gd u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
0.50	0.52110	9.71692	1.12763	0.05217	0.46212	9.66475	2.1640	0.33525	27°31′
.51	.53240	.72624	.13289	.05419	.46995	.67205	.1279	.32795	28 02
.52	.54375	.73540	.13827	.05625	.47770	.67916	.0934	.32084	28 32
.53	.55516	.74442	.14377	.05834	.48538	.68608	.0602	.31392	29 02
.54	.56663	.75330	.14938	.06046	.49299	.69284	.0284	.30716	29 32
0.55	0.57815	9.76204	1.15510	0.06262	0.50052	9.69942	1.9979	0.30058	30 02
.56	.58973	.77065	.16094	.06481	.50798	.70584	.9686	.29416	30 32
.57	.60137	.77914	.16690	.06703	.51536	.71211	.9404	.28789	31 01
.58	.61307	.78751	.17297	.06929	.52267	.71822	.9133	.28178	31 31
.59	.62483	.79576	.17916	.07157	.52990	.72419	.8872	.27581	32 00
0.60	0.63665	9.80390	1.18547	0.07389	0.53705	9.73001	1.8620	0.26999	32 29
.61	.64854	.81194	.19189	.07624	.54413	.73570	.8378	.26430	32 58
.62	.66049	.81987	.19844	.07861	.55113	.74125	.8145	.25875	33 27
63	.67251	.82770	.20510	.08102	.55805	.74667	.7919	.25333	33 55
.64	.68459	.83543	.21189	.08346	.56490	.75197	.7702	.24803	34 24
0.65	0.69675	9.84308	1.21879	0.08593	0.57167	9.75715	1.7493	0.24285	34 52
.66	.70897	.85063	.22582	.08843	.57836	.76220	.7290	.23780	35 20
.67	.72126	.85809	.23297	.09095	.58498	.76714	.7095	.23286	35 48
.68	.73363	.86548	.24025	.09351	.59152	.77197	.6906	.22803	36 16
.69	.74607	.87278	.24765	.09609	.59798	.77669	.6723	.22331	36 44
0.70	0.75858	9.88000	1.25517	0.09870	0.60437	9.78130	1.6546	0.21870	37 11
.71	.77117	.88715	.26282	.10134	.61068	.78581	.6375	.21419	37 38
.72	.78384	.89423	.27059	.10401	.61691	.79022	.6210	.20978	38 05
.73	.79659	.90123	.27849	.10670	.62307	.79453	.6050	.20547	38 32
.74	.80941	.90817	.28652	.10942	.62915	.79875	.5895	.20125	38 59
0.75	0.82232	9.91504	1.29468	0.11216	0.63515	9.80288	1.5744	0.19712	39 26
.76	.83530	.92185	.30297	.11493	.64108	.80691	.5599	.19309	39 52
.77	.84838	.92859	.31139	.11773	.64693	.81086	.5458	.18914	40 19
.78	.86153	.93527	.31994	.12055	.65271	.81472	.5321	.18528	40 45
.79	.87478	.94190	.32862	.12340	.65841	.81850	.5188	.18150	41 11
0.80	0.88811	9.94846	1.33743	0.12627	0.66404	9.82219	1.5059	0.17781	41 37
.81	.90152	.95498	.34638	.12917	.66959	.82581	.4935	.17419	42 02
.82	.91503	.96144	.35547	.13209	.67507	.82935	.4813	.17065	42 28
.83	.92863	.96784	.36468	.13503	.68048	.83281	.4696	.16719	42 53
.84	.94233	.97420	.37404	.13800	.68581	.83620	.4581	.16380	43 18
0.85	0.95612	9.98051	1.38353	0.14099	0.69107	9.83952	1.4470	0.16048	43 43
.86	.97000	.98677	.39316	.14400	.69626	.84277	.4362	.15723	44 08
.87	.98398	.99299	.40293	.14704	.70137	.84595	.4258	.15405	44 32
.88	.99806	.99916	.41284	.15009	.70642	.84906	.4156	.15094	44 57
.89	1.01224	0.00528	.42289	.15317	.71139	.85211	.4057	.14789	45 21
0.90	1.02652	0.01137	1.43309	0.15627	0.71630	9.85509	1.3961	0.14491	45 45
.91	.04090	.01741	.44342	.15939	.72113	.85801	.3867	.14199	46 09
.92	.05539	.02341	.45390	.16254	.72590	.86088	.3776	.13912	46 33
.93	.06998	.02937	.46453	.16570	.73059	.86368	.3687	.13632	46 56
.94	.08468	.03530	.47530	.16888	.73522	.86642	.3601	.13358	47 20
0.95	1.09948	0.04119	1.48623	0.17208	0.73978	9.86910	1.3517	0.13090	47 43
.96	.11440	.04704	.49729	.17531	.74428	.87173	.3436	.12827	48 06
.97	.12943	.05286	.50851	.17855	.74870	.87431	.3356	.12569	48 29
.98	.14457	.05864	.51988	.18181	.75307	.87683	.3279	.12317	48 51
.99	.15983	.06439	.53141	.18509	.75736	.87930	.3204	.12070	49 14
1.00	1.17520	0.07011	1.54308	0.18839	0.76159	9.88172	1.3130	0.11828	49 36

HYPERBOLIC FUNCTIONS

u	sinh u		cosh u		tanh u		coth u		gd u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
1.00	1.17520	0.07011	1.54308	0.18839	0.76159	9.88172	1.3130	0.11828	49° 36′
.01	.19069	.07580	.55491	.19171	.76576	.88409	.3059	.11591	49 58
.02	.20630	.08146	.56689	.19504	.76987	.88642	.2989	.11358	50 21
.03	.22203	.08708	.57904	.19839	.77391	.88869	.2921	.11131	50 42
.04	.23788	.09268	.59134	.20176	.77789	.89092	.2855	.10908	51 04
1.05	1.25386	0.09825	1.60379	0.20515	0.78181	9.89310	1.2791	0.10690	51 26
.06	.26996	.10379	.61641	.20855	.78566	.89524	.2728	.10476	51 47
.07	.28619	.10930	.62919	.21197	.78946	.89733	.2667	.10267	52 08
.08	.30254	.11479	.64214	.21541	.79320	.89938	.2607	.10062	52 29
.09	.31903	.12025	.65525	.21886	.79688	.90139	.2549	.09861	52 50
1.10	1.33565	0.12569	1.66852	0.22233	0.80050	9.90336	1.2492	0.09664	53 11
.11	.35240	.13111	.68196	.22582	.80406	.90529	.2437	.09471	53 31
.12	.36929	.13649	.69557	.22931	.80757	.90718	.2383	.09282	53 52
.13	.38631	.14186	.70934	.23283	.81102	.90903	.2330	.09097	54 12
.14	.40347	.14720	.72329	.23636	.81441	.91085	.2279	.08915	54 32
1.15	1.42078	0.15253	1.73741	0.23990	0.81775	9.91262	1.2229	0.08738	54 52
.16	.43822	.15783	.75171	.24346	.82104	.91436	.2180	.08564	55 11
.17	.45581	.16311	.76618	.24703	.82427	.91607	.2132	.08393	55 31
.18	.47355	.16836	.78083	.25062	.82745	.91774	.2085	.08226	55 50
.19	.49143	.17360	.79565	.25422	.83058	.91938	.2040	.08062	56 09
1.20	1.50946	0.17882	1.81066	0.25784	0.83365	9.92099	1.1995	0.07901	56 29
.21	.52764	.18402	.82584	.26146	.83668	.92256	.1952	.07744	56 47
.22	.54598	.18920	.84121	.26510	.83965	.92410	.1910	.07590	57 06
.23	.56447	.19437	.85676	.26876	.84258	.92561	.1868	.07439	57 25
.24	.58311	.19951	.87250	.27242	.84546	.92709	.1828	.07291	57 43
1.25	1.60192	0.20464	1.88842	0.27610	0.84828	9.92854	1.1789	0.07146	58 02
.26	.62088	.20975	.90454	.27979	.85106	.92996	.1750	.07004	58 20
.27	.64001	.21485	.92084	.28349	.85380	.93135	.1712	.06865	58 38
.28	.65930	.21993	.93734	.28721	.85648	.93272	.1676	.06728	58 55
.29	.67876	.22499	.95403	.29093	.85913	.93406	.1640	.06594	59 13
1.30	1.69838	0.23004	1.97091	0.29467	0.86172	9.93537	1.1605	0.06463	59 31
.31	.71818	.23507	.98800	.29842	.86428	.93665	.1570	.06335	59 48
.32	.73814	.24009	2.00528	.30217	.86678	.93791	.1537	.06209	60 05
.33	.75828	.24509	.02276	.30594	.86925	.93914	.1504	.06086	60 22
.34	.77860	.25008	.04044	.30972	.87167	.94035	.1472	.05965	60 39
1.35	1.79909	0.25505	2.05833	0.31352	0.87405	9.94154	1.1441	0.05846	60 56
.36	.81977	.26002	.07643	.31732	.87639	.94270	.1410	.05730	61 13
.37	.84062	.26496	.09473	.32113	.87869	.94384	.1381	.05616	61 29
.38	.86166	.26990	.11324	.32495	.88095	.94495	.1351	.05505	61 45
.39	.88289	.27482	.13196	.32878	.88317	.94601	.1323	.05396	62 02
1.40	1.90430	0.27974	2.15090	0.33262	0.88535	9.94712	1.1295	0.05288	62 18
.41	.92591	.28464	.17005	.33647	.88749	.94817	.1268	.05183	62 34
.42	.94770	.28952	.18942	.34033	.88960	.94919	.1241	.05081	62 49
.43	.96970	.29440	.20900	.34420	.89167	.95020	.1215	.04980	63 05
.44	.99188	.29926	.22881	.34807	.89370	.95119	.1189	.04881	63 20
1.45	2.01427	0.30412	2.24884	0.35196	0.89569	9.95216	1.1165	0.04784	63 36
.46	.03686	.30896	.26910	.35585	.89765	.95311	.1140	.04689	63 51
.47	.05965	.31379	.28958	.35976	.89958	.95404	.1116	.04596	64 06
.48	.08265	.31862	.31029	.36367	.90147	.95495	.1093	.04505	64 21
.49	.10586	.32343	.33123	.36759	.90332	.95584	.1070	.04416	64 36
1.50	2.12928	0.32823	2.35241	0.37151	0.90515	9.95672	1.1048	0.04328	64 51

Table 17 *(continued)*

HYPERBOLIC FUNCTIONS

u	sinh u Nat.	sinh u Log.	cosh u Nat.	cosh u Log.	tanh u Nat.	tanh u Log.	coth u Nat.	coth u Log.	gd u
1.50	2.12928	0.32823	2.35241	0.37151	0.90515	9.95672	1.1048	0.04328	64° 51′
.51	.15291	.33303	.37382	.37545	.90694	.95758	.1026	.04242	65 05
.52	.17676	.33781	.39547	.37939	.90870	.95842	.1005	.04158	65 20
.53	.20082	.34258	.41736	.38334	.91042	.95924	.0984	.04076	65 34
.54	.22510	.34735	.43949	.38730	.91212	.96005	.0963	.03995	65 48
1.55	2.24961	0.35211	2.46186	0.39126	0.91379	9.96084	1.0943	0.03916	66 02
.56	.27434	.35686	.48448	.39524	.91542	.96162	.0924	.03838	66 16
.57	.29930	.36160	.50735	.39921	.91703	.96238	.0905	.03762	66 30
.58	.32449	.36633	.53047	.40320	.91860	.96313	.0886	.03687	66 43
.59	.34991	.37105	.55384	.40719	.92015	.96386	.0868	.03614	66 57
1.60	2.37557	0.37577	2.57746	0.41119	0.92167	9.96457	1.0850	0.03543	67 10
.61	40146	.38048	.60135	.41520	.92316	.96528	.0832	.03472	67 24
.62	.42760	.38518	.62549	.41921	.92462	.96597	.0815	.03403	67 37
.63	.45397	.38987	.64990	.42323	.92606	.96664	.0798	.03336	67 50
.64	.48059	.39456	.67457	.42725	.92747	.96730	.0782	.03270	68 03
1.65	2.50746	0.39923	2.69951	0.43129	0.92886	9.96795	1.0766	0.03205	68 15
.66	.53459	.40391	.72472	.43532	.93022	.96858	.0750	.03142	68 28
.67	.56196	.40857	.75021	.43937	.93155	.96921	.0735	.03079	68 41
.68	.58959	.41323	.77596	.44341	.93286	.96982	.0720	.03018	68 53
.69	.61748	.41788	.80200	.44747	.93415	.97042	.0705	.02958	69 05
1.70	2.64563	0.42253	2.82832	0.45153	0.93541	9.97100	1.0691	0.02900	69 18
.71	.67405	.42717	.85491	.45559	.93665	.97158	.0676	.02842	69 30
.72	.70273	.43180	.88180	.45966	.93786	.97214	.0663	.02786	69 42
.73	.73168	.43643	.90897	.46374	.93906	.97269	.0649	.02731	69 54
.74	.76091	.44105	.93643	.46782	.94023	.97323	.0636	.02677	70 05
1.75	2.79041	0.44567	2.96419	0.47191	0.94138	9.97376	1.0623	0.02624	70 17
.76	.82020	.45028	.99224	.47600	.94250	.97428	.0610	.02572	70 29
.77	.85026	.45488	3.02059	.48009	.94361	.97479	.0598	.02521	70 40
.78	.88061	.45948	.04925	.48419	.94470	.97529	.0585	.02471	70 51
.79	.91125	.46408	.07821	.48830	.94576	.97578	.0574	.02422	71 03
1.80	2.94217	0.46867	3.10747	0.49241	0.94681	9.97626	1.0562	0.02374	71 14
.81	.97340	.47325	.13705	.49652	.94783	.97673	.0550	.02327	71 25
.82	3.00492	.47783	.16694	.50064	.94884	.97719	.0539	.02281	71 36
.83	.03674	.48241	.19715	.50476	.94983	.97764	.0528	.02236	71 46
.84	.06886	.48698	.22768	.50889	.95080	.97809	.0518	.02191	71 57
1.85	3.10129	0.49154	3.25853	0.51302	0.95175	9.97852	1.0507	0.02148	72 08
.86	.13403	.49610	.28970	.51716	.95268	.97895	.0497	.02105	72 18
.87	.16709	.50066	.32121	.52130	.95359	.97936	.0487	.02064	72 29
.88	.20046	.50521	.35305	.52544	.95449	.97977	.0477	.02023	72 39
.89	.23415	.50976	.38522	.52959	.95537	.98017	.0467	.01983	72 49
1.90	3.26816	0.51430	3.41773	0.53374	0.95624	9.98057	1.0458	0.01943	72 59
.91	.30250	.51884	.45058	.53789	.95709	.98095	.0448	.01905	73 09
.92	.33718	.52338	.48378	.54205	.95792	.98133	.0439	.01867	73 19
.93	.37218	.52791	.51733	.54621	.95873	.98170	.0430	.01830	73 29
.94	.40752	.53244	.55123	.55038	.95953	.98206	.0422	.01794	73 39
1.95	3.44321	0.53696	3.58548	0.55455	0.96032	9.98242	1.0413	0.01758	73 48
.96	.47923	.54148	.62009	.55872	.96109	.98276	.0405	.01724	73 58
.97	.51561	.54600	.65507	.56290	.96185	.98311	.0397	.01689	74 07
.98	.55234	.55051	.69041	.56707	.96259	.98344	.0389	.01656	74 17
.99	.58942	.55502	.72611	.57126	.96331	.98377	.0381	.01623	74 26
2.00	3.62686	0.55953	3.76220	0.57544	0.96403	9.98409	1.0373	0.01591	74 35

HYPERBOLIC FUNCTIONS

u	sinh u		cosh u		tanh u		coth u		gd u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
2.00	3.62686	0.55953	3.76220	0.57544	0.96403	9.98409	1.0373	0.01591	74°35′
.01	.66466	.56403	.79865	.57963	.96473	.98440	.0366	.01560	74 44
.02	.70283	.56853	.83549	.58382	.96541	.98471	.0358	.01529	74 53
.03	.74138	.57303	.87271	.58802	.96609	.98502	.0351	.01498	75 02
.04	.78029	.57753	.91032	.59221	.96675	.98531	.0344	.01469	75 11
2.05	3.81958	0.58202	3.94832	0.59641	0.96740	9.98560	1.0337	0.01440	75 20
.06	.85926	.58650	.98671	.60061	.96803	.98589	.0330	.01411	75 28
.07	.89932	.59099	4.02550	.60482	.96865	.98617	.0324	.01383	75 37
.08	.93977	.59547	.06470	.60903	.96926	.98644	.0317	.01356	75 45
.09	.98061	.59995	.10430	.61324	.96986	.98671	.0311	.01329	75 54
2.10	4.02186	0.60443	4.14431	0.61745	0.97045	9.98697	1.0304	0.01303	76 02
.11	.06350	.60890	.18474	.62167	.97103	.98723	.0298	.01277	76 10
.12	.10555	.61337	.22558	.62589	.97159	.98748	.0292	.01252	76 19
.13	.14801	.61784	.26685	.63011	.97215	.98773	.0286	.01227	76 27
.14	.19089	.62231	.30855	.63433	.97269	.98798	.0281	.01202	76 35
2.15	4.23419	0.62677	4.35067	0.63856	0.97323	9.98821	1.0275	0.01179	76 43
.16	.27791	.63123	.39323	.64278	.97375	.98845	.0270	.01155	76 51
	.32205	.63569	.43623	.64701	.97426	.98868	.0264	.01132	76 58
.18	.36663	.64015	.47967	.65125	.97477	.98890	.0259	.01110	77 06
.19	.41165	.64460	.52356	.65548	.97526	.98912	.0254	.01088	77 14
2.20	4.45711	0.64905	4.56791	0.65972	0.97574	9.98934	1.0249	0.01066	77 21
.21	.50301	.65350	.61271	.66396	.97622	.98955	.0244	.01045	77 29
.22	.54936	.65795	.65797	.66820	.97668	.98975	.0239	.01025	77 36
.23	.59617	.66240	.70370	.67244	.97714	.98996	.0234	.01004	77 44
.24	.64344	.66684	.74989	.67668	.97759	.99016	.0229	.00984	77 51
2.25	4.69117	0.67128	4.79657	0.68093	0.97803	9.99035	1.0225	0.00965	77 58
.26	.73937	.67572	.84372	.68518	.97846	.99054	.0220	.00946	78 05
.27	.78804	.68016	.89136	.68943	.97888	.99073	.0216	.00927	78 12
.28	.83720	.68459	.93948	.69368	.97929	.99091	.0211	.00909	78 19
.29	.88684	.68903	.98810	.69794	.97970	.99109	.0207	.00891	78 26
2.30	4.93696	0.69346	5.03722	0.70219	0.98010	9.99127	1.0203	0.00873	78 33
.31	.98758	.69789	.08684	.70645	.98049	.99144	.0199	.00856	78 40
.32	5.03870	.70232	.13697	.71071	.98087	.99161	.0195	.00839	78 46
.33	.09032	.70675	.18762	.71497	.98124	.99178	.0191	.00822	78 53
.34	.14245	.71117	.23878	.71923	.98161	.99194	.0187	.00806	79 00
2.35	5.19510	0.71559	5.29047	0.72349	0.98197	9.99210	1.0184	0.00790	79 06
.36	.24827	.72002	.34269	.72776	.98233	.99226	.0180	.00774	79 13
.37	.30196	.72444	.39544	.73203	.98267	.99241	.0176	.00759	79 19
.38	.35618	.72885	.44873	.73630	.98301	.99256	.0173	.00744	79 25
.39	.41093	.73327	.50256	.74056	.98335	.99271	.0169	.00729	79 32
2.40	5.46623	0.73769	5.55695	0.74484	0.98367	9.99285	1.0166	0.00715	79 38
.41	.52207	.74210	.61189	.74911	.98400	.99299	.0163	.00701	79 44
.42	.57847	.74652	.66739	.75338	.98431	.99313	.0159	.00687	79 50
.43	.63542	.75093	.72346	.75766	.98462	.99327	.0156	.00673	79 56
.44	.69294	.75534	.78010	.76194	.98492	.99340	.0153	.00660	80 02
2.45	5.75103	0.75975	5.83732	0.76621	0.98522	9.99353	1.0150	0.00647	80 08
.46	.80969	.76415	.89512	.77049	.98551	.99366	.0147	.00634	80 14
.47	.86893	.76856	.95352	.77477	.98579	.99379	.0144	.00621	80 20
.48	.92876	.77296	6.01250	.77906	.98607	.99391	.0141	.00609	80 26
.49	.98918	.77737	.07209	.78334	.98635	.99403	.0138	.00597	80 31
2.50	6.05020	0.78177	6.13229	0.78762	0.98661	9.99415	1.0136	0.00585	80 37

TABLE 17 *(continued)*

HYPERBOLIC FUNCTIONS

u	sinh u		cosh u		tanh u		coth u		gd u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
2.50	6.05020	0.78177	6.13229	0.78762	0.98661	9.99415	1.0136	0.00585	80° 37′
.51	.11183	.78617	.19310	.79191	.98688	.99426	.0133	.00574	80 42
.52	.17407	.79057	.25453	.79619	.98714	.99438	.0130	.00562	80 48
.53	.23692	.79497	.31658	.80048	.98739	.99449	.0128	.00551	80 53
.54	.30040	.79937	.37927	.80477	.98764	.99460	.0125	.00540	80 59
2.55	6.36451	0.80377	6.44259	0.80906	0.98788	9.99470	1.0123	0.00530	81 04
.56	.42926	.80816	.50656	.81335	.98812	.99481	.0120	.00519	81 10
.57	.49464	.81256	.57118	.81764	.98835	.99491	.0118	.00509	81 15
.58	.56068	.81695	.63646	.82194	.98858	.99501	.0115	.00499	81 20
.59	.62738	.82134	.70240	.82623	.98881	.99511	.0113	.00489	81 25
2.60	6.69473	0.82573	6.76901	0.83052	0.98903	9.99521	1.0111	0.00479	81 30
.61	.76276	.83012	.83629	.83482	.98924	.99530	.0109	.00470	81 35
.62	.83146	.83451	.90426	.83912	.98946	.99540	.0107	.00460	81 40
.63	.90085	.83890	.97292	.84341	.98966	.99549	.0104	.00451	81 45
.64	.97092	.84329	7.04228	.84771	.98987	.99558	.0102	.00442	81 50
2.65	7.04169	0.84768	7.11234	0.85201	0.99007	9.99566	1.0100	0.00434	81 55
.66	.11317	.85206	.18312	.85631	.99026	.99575	.0098	.00425	82 00
.67	.18536	.85645	.25461	.86061	.99045	.99583	.0096	.00417	82 05
.68	.25827	.86083	.32683	.86492	.99064	.99592	.0094	.00408	82 09
.69	.33190	.86522	.39978	.86922	.99083	.99600	.0093	.00400	82 14
2.70	7.40626	0.86960	7.47347	0.87352	0.99101	9.99608	1.0091	0.00392	82 19
.71	.48137	.87398	.54791	.87783	.99118	.99615	.0089	.00385	82 23
.72	.55722	.87836	.62310	.88213	.99136	.99623	.0087	.00377	82 28
.73	.63383	.88274	.69905	.88644	.99153	.99631	.0085	.00369	82 32
.74	.71121	.88712	.77578	.89074	.99170	.99638	.0084	.00362	82 37
2.75	7.78935	0.89150	7.85328	0.89505	0.99186	9.99645	1.0082	0.00355	82 41
.76	.86828	.89588	.93157	.89936	.99202	.99652	.0080	.00348	82 45
.77	.94799	.90026	8.01065	.90367	.99218	.99659	.0079	.00341	82 50
.78	8.02849	.90463	.09053	.90798	.99233	.99666	.0077	.00334	82 54
.79	.10980	.90901	.17122	.91229	.99248	.99672	.0076	.00328	82 58
2.80	8.19192	0.91339	8.25273	0.91660	0.99263	9.99679	1.0074	0.00321	83 02
.81	.27486	.91776	.33506	.92091	.99278	.99685	.0073	.00315	83 07
.82	.35862	.92213	.41823	.92522	.99292	.99691	.0071	.00309	83 11
.83	.44322	.92651	.50224	.92953	.99306	.99698	.0070	.00302	83 15
.84	.52867	.93088	.58710	.93385	.99320	.99704	.0069	.00296	83 19
2.85	8.61497	0.93525	8.67281	0.93816	0.99333	9.99709	1.0067	0.00291	83 23
.86	.70213	.93963	.75940	.94247	.99346	.99715	.0066	.00285	83 27
.87	.79016	.94400	.84686	.94679	.99359	.99721	.0065	.00279	83 31
.88	.87907	.94837	.93520	.95110	.99372	.99726	.0063	.00274	83 34
.89	.96887	.95274	9.02444	.95542	.99384	.99732	.0062	.00268	83 38
2.90	9.05956	0.95711	9.11458	0.95974	0.99396	9.99737	1.0061	0.00263	83 42
.91	.15116	.96148	.20564	.96405	.99408	.99742	.0060	.00258	83 46
.92	.24368	.96584	.29761	.96837	.99420	.99747	.0058	.00253	83 50
.93	.33712	.97021	.39051	.97269	.99531	.99752	.0057	.00248	83 53
.94	.43149	.97458	.48436	.97701	.99443	.99757	.0056	.00243	83 57
2.95	9.52681	0.97895	9.57915	0.98133	0.99454	9.99762	1.0055	0.00238	84 00
.96	.62308	.98331	.67490	.98565	.99464	.99767	.0054	.00233	84 04
.97	.72031	.98768	.77161	.98997	.99475	.99771	.0053	.00229	84 08
.98	.81851	.99205	.86930	.99429	.99485	.99776	.0052	.00224	84 11
.99	.91770	.99641	.96798	.99861	.99496	.99780	.0051	.00220	84 15
3.00	10.01787	1.00078	10.06766	1.00293	0.99505	9.99785	1.0050	0.00215	84 18

TABLE 17 (*concluded*).—HYPERBOLIC FUNCTIONS

u	sinh u		cosh u		tanh u		coth u		gd u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
3.0	10.0179	1.00078	10.0677	1.00293	0.99505	9.99785	1.0050	0.00215	84°18′
.1	11.0765	.04440	11.1215	.04616	.99595	.99824	.0041	.00176	84 50
.2	12.2459	.08799	12.2866	.08943	.99668	.99856	.0033	.00144	85 20
.3	13.5379	.13155	13.5748	.13273	.99728	.99882	.0027	.00118	85 47
.4	14.9654	.17509	14.9987	.17605	.99777	.99903	.0022	.00097	86 11
3.5	16.5426	1.21860	16.5728	1.21940	0.99818	9.99921	1.0018	0.00079	86 32
.6	18.2855	.26211	18.3128	.26275	.99851	.99935	.0015	.00065	86 52
.7	20.2113	.30559	20.2360	.30612	.99878	.99947	.0012	.00053	87 10
.8	22.3394	.34907	22.3618	.34951	.99900	.99957	.0010	.00043	87 26
.9	24.6911	.39254	24.7113	.39290	.99918	.99964	.0008	.00036	87 41
4.0	27.2899	1.43600	27.3082	1.43629	0.99933	9.99971	1.0007	0.00029	87 54
.1	30.1619	.47946	30.1784	.47970	.99945	.99976	.0005	.00024	88 06
.2	33.3357	.52291	33.3507	.52310	.99955	.99980	.0004	.00020	88 17
.3	36.8431	.56636	36.8567	.56652	.99963	.99984	.0004	.00016	88 27
.4	40.7193	.60980	40.7316	.60993	.99970	.99987	.0003	.00013	88 36
4.5	45.0030	1.65324	45.0141	1.65335	0.99975	9.99989	1.0002	0.00011	88 44
.6	49.7371	.69668	49.7472	.69677	.99980	.99991	.0002	.00009	88 51
.7	54.9690	.74012	54.9781	.74019	.99983	.99993	.0002	.00007	88 57
.8	60.7511	.78355	60.7593	.78361	.99986	.99994	.0001	.00006	89 03
.9	67.1412	.82699	67.1486	.82704	.99989	.99995	.0001	.00005	89 09
5.0	74.2032	1.87042	74.2099	1.87046	0.99991	9.99996	1.0001	0.00004	89 14

TABLE 18.—Factorials

See Table 16 for logarithms of the products 1.2.3. . . . n from 1 to 100.

See Table 33 for log. $\Gamma(n+1)$ for values of n between 1.000 and 2.000.

n	$\frac{1}{n!}$	$n! = 1.2.3.4 \ldots n$	n
1	1.	1	1
2	0.5	2	2
3	.16666 66666 66666 66666 66667	6	3
4	.04166 66666 66666 66666 66667	24	4
5	.00833 33333 33333 33333 33333	120	5
6	0.00138 88888 88888 88888 88889	720	6
7	.00019 84126 98412 69841 26984	5040	7
8	.00002 48015 87301 58730 15873	40320	8
9	.00000 27557 31922 39858 90653	3 62880	9
10	.00000 02755 73192 23985 89065	36 28800	10
11	0.00000 00250 52108 38544 17188	399 16800	11
12	.00000 00020 87675 69878 68099	4790 01600	12
13	.00000 00001 60590 43836 82161	62270 20800	13
14	.00000 00000 11470 74559 77297	8 71782 91200	14
15	.00000 00000 00764 71637 31820	130 76743 68000	15
16	0.00000 00000 00047 79477 33239	2092 27898 88000	16
17	.00000 00000 00002 81145 72543	35568 74280 96000	17
18	.00000 00000 00000 15619 20697	6 40237 37057 28000	18
19	.00000 00000 00000 00822 06352	121 64510 04088 32000	19
20	.00000 00000 00000 00041 10318	2432 90200 81766 40000	20

TABLE 19

EXPONENTIAL FUNCTIONS

x	$\log_{10}(e^x)$	e^x	e^{-x}	x	$\log_{10}(e^x)$	e^x	e^{-x}
0.00	0.00000	1.0000	1.000000	0.50	0.21715	1.6487	0.606531
.01	.00434	.0101	0.990050	.51	.22149	.6653	.600496
.02	.00869	.0202	.980199	.52	.22583	.6820	.594521
.03	.01303	.0305	.970446	.53	.23018	.6989	.588605
.04	.01737	.0408	.960789	.54	.23452	.7160	.582748
0.05	0.02171	1.0513	0.951229	0.55	0.23886	1.7333	0.576950
.06	.02606	.0618	.941765	.56	.24320	.7507	.571209
.07	.03040	.0725	.932394	.57	.24755	.7683	.565525
.08	.03474	.0833	.923116	.58	.25189	.7860	.559898
.09	.03909	.0942	.913931	.59	.25623	.8040	.554327
0.10	0.04343	1.1052	0.904837	0.60	0.26058	1.8221	0.548812
.11	.04777	.1163	.895834	.61	.26492	.8404	.543351
.12	.05212	.1275	.886920	.62	.26926	.8589	.537944
.13	.05646	.1388	.878095	.63	.27361	.8776	.532592
.14	.06080	.1503	.869358	.64	.27795	.8965	.527292
0.15	0.06514	1.1618	0.860708	0.65	0.28229	1.9155	0.522046
.16	.06949	.1735	.852144	.66	.28663	.9348	.516851
.17	.07383	.1853	.843665	.67	.29098	.9542	.511709
.18	.07817	.1972	.835270	.68	.29532	.9739	.506617
.19	.08252	.2092	.826959	.69	.29966	.9937	.501576
0.20	0.08686	1.2214	0.818731	0.70	0.30401	2.0138	0.496585
.21	.09120	.2337	.810584	.71	.30835	.0340	.491644
.22	.09554	.2461	.802519	.72	.31269	.0544	.486752
.23	.09989	.2586	.794534	.73	.31703	.0751	.481909
.24	.10423	.2712	.786628	.74	.32138	.0959	.477114
0.25	0.10857	1.2840	0.778801	0.75	0.32572	2.1170	0.472367
.26	.11292	.2969	.771052	.76	.33006	.1383	.467666
.27	.11726	.3100	.763379	.77	.33441	.1598	.463013
.28	.12160	.3231	.755784	.78	.33875	.1815	.458406
.29	.12595	.3364	.748264	.79	.34309	.2034	.453845
0.30	0.13029	1.3499	0.740818	0.80	0.34744	2.2255	0.449329
.31	.13463	.3634	.733447	.81	.35178	.2479	.444858
.32	.13897	.3771	.726149	.82	.35612	.2705	.440432
.33	.14332	.3910	.718924	.83	.36046	.2933	.436049
.34	.14766	.4049	.711770	.84	.36481	.3164	.431711
0.35	0.15200	1.4191	0.704688	0.85	0.36915	2.3396	0.427415
.36	.15635	.4333	.697676	.86	.37349	.3632	.423162
.37	.16069	.4477	.690734	.87	.37784	.3869	.418952
.38	.16503	.4623	.683861	.88	.38218	.4109	.414783
.39	.16937	.4770	.677057	.89	.38652	.4351	.410656
0.40	0.17372	1.4918	0.670320	0.90	0.39087	2.4596	0.406570
.41	.17806	.5068	.663650	.91	.39521	.4843	.402524
.42	.18240	.5220	.657047	.92	.39955	.5093	.398519
.43	.18675	.5373	.650509	.93	.40389	.5345	.394554
.44	.19109	.5527	.644036	.94	.40824	.5600	.390628
0.45	0.19543	1.5683	0.637628	0.95	0.41258	2.5857	0.386741
.46	.19978	.5841	.631284	.96	.41692	.6117	.382893
.47	.20412	.6000	.625002	.97	.42127	.6379	.379083
.48	.20846	.6161	.618783	.98	.42561	.6645	.375311
.49	.21280	.6323	.612626	.99	.42995	.6912	.371577
0.50	0.21715	1.6487	0.606531	1.00	0.43429	2.7183	0.367879

EXPONENTIAL FUNCTIONS

x	$\log_{10}(e^x)$	e^x	e^{-x}	x	$\log_{10}(e^x)$	e^x	e^{-x}
1.00	0.43429	2.7183	0.367879	1.50	0.65144	4.4817	0.223130
.01	.43864	.7456	.364219	.51	.65578	.5267	.220910
.02	.44298	.7732	.360595	.52	.66013	.5722	.218712
.03	.44732	.8011	.357007	.53	.66447	.6182	.216536
.04	.45167	.8292	.353455	.54	.66881	.6646	.214381
1.05	0.45601	2.8577	0.349938	1.55	0.67316	4.7115	0.212248
.06	.46035	.8864	.346456	.56	.67750	.7588	.210136
.07	.46470	.9154	.343009	.57	.68184	.8066	.208045
.08	.46904	.9447	.339596	.58	.68619	.8550	.205975
.09	.47338	.9743	.336216	.59	.69053	.9037	.203926
1.10	0.47772	3.0042	0.332871	1.60	0.69487	4.9530	0.201897
.11	.48207	.0344	.329559	.61	.69921	5.0028	.199888
.12	.48641	.0649	.326280	.62	.70356	.0531	.197899
.13	.49075	.0957	.323033	.63	.70790	.1039	.195930
.14	.49510	.1268	.319819	.64	.71224	.1552	.193980
1.15	0.49944	3.1582	0.316637	1.65	0.71659	5.2070	0.192050
.16	.50378	.1899	.313486	.66	.72093	.2593	.190139
.17	.50812	.2220	.310367	.67	.72527	.3122	.188247
.18	.51247	.2544	.307279	.68	.72961	.3656	.186374
.19	.51681	.2871	.304221	.69	.73396	.4195	.184520
1.20	0.52115	3.3201	0.301194	1.70	0.73830	5.4739	0.182684
.21	.52550	.3535	.298197	.71	.74264	.5290	.180866
.22	.52984	.3872	.295230	.72	.74699	.5845	.179066
.23	.53418	.4212	.292293	.73	.75133	.6407	.177284
.24	.53853	.4556	.289384	.74	.75567	.6973	.175520
1.25	0.54287	3.4903	0.286505	1.75	0.76002	5.7546	0.173774
.26	.54721	.5254	.283654	.76	.76436	.8124	.172045
.27	.55155	.5609	.280832	.77	.76870	.8709	.170333
.28	.55590	.5966	.278037	.78	.77304	.9299	.168638
.29	.56024	.6328	.275271	.79	.77739	.9895	.166960
1.30	0.56458	3.6693	0.272532	1.80	0.78173	6.0496	0.165299
.31	.56893	.7062	.269820	.81	.78607	.1104	.163654
.32	.57327	.7434	.267135	.82	.79042	.1719	.162026
.33	.57761	.7810	.264477	.83	.79476	.2339	.160414
.34	.58195	.8190	.261846	.84	.79910	.2965	.158817
1.35	0.58630	3.8574	0.259240	1.85	0.80344	6.3598	0.157237
.36	.59064	.8962	.256661	.86	.80779	.4237	.155673
.37	.59498	.9354	.254107	.87	.81213	.4883	.154124
.38	.59933	.9749	.251579	.88	.81647	.5535	.152590
.39	.60367	4.0149	.249075	.89	.82082	.6194	.151072
1.40	0.60801	4.0552	0.246597	1.90	0.82516	6.6859	0.149569
.41	.61236	.0960	.244143	.91	.82950	.7531	.148080
.42	.61670	.1371	.241714	.92	.83385	.8210	.146607
.43	.62104	.1787	.239309	.93	.83819	.8895	.145148
.44	.62538	.2207	.236928	.94	.84253	.9588	.143704
1.45	0.62973	4.2631	0.234570	1.95	0.84687	7.0287	0.142274
.46	.63407	.3060	.232236	.96	.85122	.0993	.140858
.47	.63841	.3492	.229925	.97	.85556	.1707	.139457
.48	.64276	.3929	.227638	.98	.85990	.2427	.138069
.49	.64710	.4371	.225373	.99	.86425	.3155	.136695
1.50	0.65144	4.4817	0.223130	2.00	0.86859	7.3891	0.135335

EXPONENTIAL FUNCTIONS

x	$\log_{10}(e^x)$	e^x	e^{-x}	x	$\log_{10}(e^x)$	e^x	e^{-x}
2.00	0.86859	7.3891	0.135335	2.50	1.08574	12.182	0.082085
.01	.87293	.4633	.133989	.51	.09008	.305	.081268
.02	.87727	.5383	.132655	.52	.09442	.429	.080460
.03	.88162	.6141	.131336	.53	.09877	.554	.079659
.04	.88596	.6906	.130029	.54	.10311	.680	.078866
2.05	0.89030	7.7679	0.128735	2.55	1.10745	12.807	0.078082
.06	.89465	.8460	.127454	.56	.11179	.936	.077305
.07	.89899	9248	.126186	.57	.11614	13.066	.076536
.08	.90333	8.0045	.124930	.58	.12048	.197	.075774
.09	.90768	.0849	.123687	.59	.12482	.330	.075020
2.10	0.91202	8.1662	0.122456	2.60	1.12917	13.464	0.074274
.11	.91636	.2482	.121238	.61	.13351	.599	.073535
.12	92070	.3311	.120032	.62	.13785	.736	.072803
.13	.92505	.4149	.118837	.63	.14219	.874	.072078
.14	.92939	.4994	.117655	.64	.14654	14.013	.071361
2.15	0.93373	8.5849	0.116484	2.65	1.15088	14.154	0.070651
.16	.93808	.6711	.115325	.66	.15522	.296	.069948
.17	.94242	.7583	.114178	.67	.15957	.440	.069252
.18	.94676	.8463	.113042	.68	.16391	.585	.068563
.19	.95110	.9352	.111917	.69	.16825	.732	.067881
2.20	0.95545	9.0250	0.110803	2.70	1.17260	14.880	0.067206
.21	.95979	.1157	.109701	.71	.17694	15.029	.066537
.22	.96413	.2073	.108609	.72	.18128	.180	.065875
.23	.96848	.2999	.107528	.73	.18562	.333	.065219
.24	.97282	.3933	.106459	.74	.18997	.487	.064570
2.25	0.97716	9.4877	0.105399	2.75	1.19431	15.643	0.063928
.26	.98151	.5831	.104350	.76	.19865	.800	.063292
.27	.98585	.6794	.103312	.77	.20300	.959	.062662
.28	.99019	.7767	.102284	.78	.20734	16.119	.062039
.29	.99453	.8749	.101266	.79	.21168	.281	.061421
2.30	0.99888	9.9742	0.100259	2.80	1.21602	16.445	0.060810
.31	1.00322	10.074	.099261	.81	.22037	.610	.060205
.32	.00756	.176	.098274	.82	.22471	.777	.059606
.33	.01191	.278	.097296	.83	.22905	.945	.059013
.34	.01625	.381	.096328	.84	.23340	17.116	.058426
2.35	1.02059	10.486	0.095369	2.85	1.23774	17.288	0.057844
.36	.02493	.591	.094420	.86	.24208	.462	.057269
.37	.02928	.697	.093481	.87	.24643	.637	.056699
.38	.03362	.805	.092551	.88	.25077	.814	.056135
.39	.03796	.913	.091630	.89	.25511	.993	.055576
2.40	1.04231	11.023	0.090718	2.90	1.25945	18.174	0.055023
.41	.04665	.134	.089815	.91	.26380	.357	.054476
.42	.05099	.246	.088922	.92	.26814	.541	.053934
.43	.05534	.359	.088037	.93	.27248	.728	.053397
.44	.05968	.473	.087161	.94	.27683	.916	.052866
2.45	1.06402	11.588	0.086294	2.95	1.28117	19.106	0.052340
.46	.06836	.705	.085435	.96	.28551	.298	.051819
.47	.07271	.822	.084585	.97	.28985	.492	.051303
.48	.07705	.941	.083743	.98	.29420	.688	.050793
.49	.08139	12.061	.082910	.99	.29854	.886	.050287
2.50	1.08574	12.182	0.082085	3.00	1.30288	20.086	0.049787

EXPONENTIAL FUNCTIONS

x	$\log_{10}(e^x)$	e^x	e^{-x}	x	$\log_{10}(e^x)$	e^x	e^{-x}
3.00	1.30288	20.086	0.049787	3.50	1.52003	33.115	0.030197
.01	.30723	.287	.049292	.51	.52437	.448	.029897
.02	.31157	.491	.048801	.52	.52872	.784	.029599
.03	.31591	.697	.048316	.53	.53306	34.124	.029305
.04	.32026	.905	.047835	.54	.53740	.467	.029013
3.05	1.32460	21.115	0.047359	3.55	1.54175	34.813	0.028725
.06	.32894	.328	.046888	.56	.54609	35.163	.028439
.07	.33328	.542	.046421	.57	.55043	.517	.028156
.08	.33763	.758	.045959	.58	.55477	.874	.027876
.09	.34197	.977	.045502	.59	.55912	36.234	.027598
3.10	1.34631	22.198	0.045049	3.60	1.56346	36.598	0.027324
.11	.35066	.421	.044601	.61	.56780	.966	.027052
.12	.35500	.646	.044157	.62	.57215	37.338	.026783
.13	.35934	.874	.043718	.63	.57649	.713	.026516
.14	.36368	23.104	.043283	.64	.58083	38.092	.026252
3.15	1.36803	23.336	0.042852	3.65	1.58517	38.475	0.025991
.16	.37237	.571	.042426	.66	.58952	.861	.025733
.17	.37671	.807	.042004	.67	.59386	39.252	.025476
.18	.38106	24.047	.041586	.68	.59820	.646	.025223
.19	.38540	.288	.041172	.69	.60255	40.045	.024972
3.20	1.38974	24.533	0.040762	3.70	1.60689	40.447	0.024724
.21	.39409	.779	.040357	.71	.61123	.854	.024478
.22	.39843	25.028	.039955	.72	.61558	41.264	.024234
.23	.40277	.280	.039557	.73	.61992	.679	.023993
.24	.40711	.534	.039164	.74	.62426	42.098	.023754
3.25	1.41146	25.790	0.038774	3.75	1.62860	42.521	0.023518
.26	.41580	26.050	.038388	.76	.63295	.948	.023284
.27	.42014	.311	.038006	.77	.63729	43.380	.023052
.28	.42449	.576	.037628	.78	.64163	.816	.022823
.29	.42883	.843	.037254	.79	.64598	44.256	.022596
3.30	1.43317	27.113	0.036883	3.80	1.65032	44.701	0.022371
.31	.43751	.385	.036516	.81	.65466	45.150	.022148
.32	.44186	.660	.036153	.82	.65900	.604	.021928
.33	.44620	.938	.035793	.83	.66335	46.063	.021710
.34	.45054	28.219	.035437	.84	.66769	.525	.021494
3.35	1.45489	28.503	0.035084	3.85	1.67203	46.993	0.021280
.36	.45923	.789	.034735	.86	.67638	47.465	.021068
.37	.46357	29.079	.034390	.87	.68072	.942	.020858
.38	.46792	.371	.034047	.88	.68506	48.424	.020651
.39	.47226	.666	.033709	.89	.68941	.911	.020445
3.40	1.47660	29.964	0.033373	3.90	1.69375	49.402	0.020242
.41	.48094	30.265	.033041	.91	.69809	.899	.020041
.42	.48529	.569	.032712	.92	.70243	50.400	.019841
.43	.48963	.877	.032387	.93	.70678	.907	.019644
.44	.49397	31.187	.032065	.94	.71112	51.419	.019448
3.45	1.49832	31.500	0.031746	3.95	1.71546	51.935	0.019255
.46	.50266	.817	.031430	.96	.71981	52.457	.019063
.47	.50700	32.137	.031117	.97	.72415	.985	.018873
.48	.51134	.460	.030807	.98	.72849	53.517	.018686
.49	.51569	.786	.030501	.99	.73283	54.055	.018500
3.50	1.52003	33.115	0.030197	4.00	1.73718	54.598	0.018316

TABLE 19 *(continued)*

EXPONENTIAL FUNCTIONS

x	$\log_{10}(e^x)$	e^x	e^{-x}	x	$\log_{10}(e^x)$	e^x	e^{-x}
4.00	1.73718	54.598	0.018316	4.50	1.95433	90.017	0.011109
.01	.74152	55.147	.018133	.51	.95867	.922	.010998
.02	.74586	.701	.017953	.52	.96301	91.836	.010889
.03	.75021	56.261	.017774	.53	.96735	92.759	.010781
.04	.75455	.826	.017597	.54	.97170	93.691	.010673
4.05	1.75889	57.397	0.017422	4.55	1.97604	94.632	0.010567
.06	.76324	.974	.017249	.56	.98038	95.583	.010462
.07	.76758	58.557	.017077	.57	.98473	96.544	.010358
.08	.77192	59.145	.016907	.58	.98907	97.514	.010255
.09	.77626	.740	.016739	.59	.99341	98.494	.010153
4.10	1.78061	60.340	0.016573	4.60	1.99775	99.484	0.010052
.11	.78495	.947	.016408	.61	2.00210	100.48	.009952
.12	.78929	61.559	.016245	.62	.00644	101.49	.009853
.13	.79364	62.178	.016083	.63	.01078	102.51	.009755
.14	.79798	.803	.015923	.64	.01513	103.54	.009658
4.15	1.80232	63.434	0.015764	4.65	2.01947	104.58	0.009562
.16	.80667	64.072	.015608	.66	.02381	105.64	.009466
.17	.81101	.715	.015452	.67	.02816	106.70	.009372
.18	.81535	65.366	.015299	.68	.03250	107.77	.009279
.19	.81969	66.023	.015146	.69	.03684	108.85	.009187
4.20	1.82404	66.686	0.014996	4.70	2.04118	109.95	0.009095
.21	.82838	67.357	.014846	.71	.04553	111.05	.009005
.22	.83272	68.033	.014699	.72	.04987	112.17	.008915
.23	.83707	.717	.014552	.73	.05421	113.30	.008826
.24	.84141	69.408	.014408	.74	.05856	114.43	.008739
4.25	1.84575	70.105	0.014264	4.75	2.06290	115.58	0.008652
.26	.85009	.810	.014122	.76	.06724	116.75	.008566
.27	.85444	71.522	.013982	.77	.07158	117.92	.008480
.28	.85878	72.240	.013843	.78	.07593	119.10	.008396
.29	.86312	.966	.013705	.79	.08027	120.30	.008312
4.30	1.86747	73.700	0.013569	4.80	2.08461	121.51	0.008230
.31	.87181	74.440	.013434	.81	.08896	122.73	.008148
.32	.87615	75.189	.013300	.82	.09330	123.97	.008067
.33	.88050	.944	.013168	.83	.09764	125.21	.007987
.34	.88484	76.708	.013037	.84	.10199	126.47	.007907
4.35	1.88918	77.478	0.012907	4.85	2.10633	127.74	0.007828
.36	.89352	78.257	.012778	.86	.11067	129.02	.007750
.37	.89787	79.044	.012651	.87	.11501	130.32	.007673
.38	.90221	79.838	.012525	.88	.11936	131.63	.007597
.39	.90655	80.640	.012401	.89	.12370	132.95	.007521
4.40	1.91090	81.451	0.012277	4.90	2.12804	134.29	0.007447
.41	.91524	82.269	.012155	.91	.13239	135.64	.007372
.42	.91958	83.096	.012034	.92	.13673	137.00	.007299
.43	.92392	.931	.011914	.93	.14107	138.38	.007227
.44	.92827	84.775	.011796	.94	.14541	139.77	.007155
4.45	1.93261	85.627	0.011679	4.95	2.14976	141.17	0.007083
.46	.93695	86.488	.011562	.96	.15410	142.59	.007013
.47	.94130	87.357	.011447	.97	.15844	144.03	.006943
.48	.94564	88.235	.011333	.98	.16279	145.47	.006874
.49	.94998	89.121	.011221	.99	.16713	146.94	.006806
4.50	1.95433	90.017	0.011109	5.00	2.17147	148.41	0.006738

EXPONENTIAL FUNCTIONS

x	$\log_{10}(e^x)$	e^x	e^{-x}	x	$\log_{10}(e^x)$	e^x	e^{-x}
5.00	2.17147	148.41	0.006738	5.0	2.17147	148.41	0.006738
.01	.17582	149.90	.006671	.1	.21490	164.02	.006097
.02	.18016	151.41	.006605	.2	.25833	181.27	.005517
.03	.18450	152.93	.006539	.3	.30176	200.34	.004992
.04	.18884	154.47	.006474	.4	.34519	221.41	.004517
5.05	2.19319	156.02	0.006409	5.5	2.38862	244.69	0.004087
.06	.19753	157.59	.006346	.6	.43205	270.43	.003698
.07	.20187	159.17	.006282	.7	.47548	298.87	.003346
.08	.20622	160.77	.006220	.8	.51891	330.30	.003028
.09	.21056	162.39	.006158	.9	.56234	365.04	.002739
5.10	2.21490	164.02	0.006097	6.0	2.60577	403.43	0.002479
.11	.21924	165.67	.006036	.1	.64920	445.86	.002243
.12	.22359	167.34	.005976	.2	.69263	492.75	.002029
.13	.22793	169.02	.005917	.3	.73606	544.57	.001836
.14	.23227	170.72	.005858	.4	.77948	601.85	.001662
5.15	2.23662	172.43	0.005799	6.5	2.82291	665.14	0.001503
.16	.24096	174.16	.005742	.6	.86634	735.10	.001360
.17	.24530	175.91	.005685	.7	.90977	812.41	.001231
.18	.24965	177.68	.005628	.8	.95320	897.85	.001114
.19	.25399	179.47	.005572	.9	.99663	992.27	.001008
5.20	2.25833	181.27	0.005517	7.0	3.04006	1096.6	0.000912
.21	.26267	183.09	.005462	.1	.08349	1212.0	.000825
.22	.26702	184.93	.005407	.2	.12692	1339.4	.000747
.23	.27136	186.79	.005354	.3	.17035	1480.3	.000676
.24	.27570	188.67	.005300	.4	.21378	1636.0	.000611
5.25	2.28005	190.57	0.005248	7.5	3.25721	1808.0	0.000553
.26	.28439	192.48	.005195	.6	.30064	1998.2	.000500
.27	.28873	194.42	.005144	.7	.34407	2208.3	.000453
.28	.29307	196.37	.005092	.8	.38750	2440.6	.000410
.29	.29742	198.34	.005042	.9	.43093	2697.3	.000371
5.30	2.30176	200.34	0.004992	8.0	3.47436	2981.0	0.000335
.31	.30610	202.35	.004942	.1	.51779	3294.5	.000304
.32	.31045	204.38	.004893	.2	.56121	3641.0	.000275
.33	.31479	206.44	.004844	.3	.60464	4023.9	.000249
.34	.31913	208.51	.004796	.4	.64807	4447.1	.000225
5.35	2.32348	210.61	0.004748	8.5	3.69150	4914.8	0.000203
.36	.32782	212.72	.004701	.6	.73493	5431.7	.000184
.37	.33216	214.86	.004654	.7	.77836	6002.9	.000167
.38	.33650	217.02	.004608	.8	.82179	6634.2	.000151
.39	.34085	219.20	.004562	.9	.86522	7332.0	.000136
5.40	2.34519	221.41	0.004517	9.0	3.90865	8103.1	0.000123
.41	.34953	223.63	.004472	.1	.95208	8955.3	.000112
.42	.35388	225.88	.004427	.2	.99551	9897.1	.000101
.43	.35822	228.15	.004383	.3	4.03894	10938.	.000091
.44	.36256	230.44	.004339	.4	.08237	12088.	.000083
5.45	2.36690	232.76	0.004296	9.5	4.12580	13360.	0.000075
.46	.37125	235.10	.004254	.6	.16923	14765.	.000068
.47	.37559	237.46	.004211	.7	.21266	16318.	.000061
.48	.37993	239.85	.004169	.8	.25609	18034.	.000055
.49	.38428	242.26	.004128	.9	.29952	19930.	.000050
5.50	2.38862	244.69	0.004087	10.0	4.34294	22026.	0.000045

Table 20

EXPONENTIAL FUNCTIONS

Values of e^{x^2} and e^{-x^2} and their logarithms

x	e^{x^2}	$\log e^{x^2}$	e^{-x^2}	$\log e^{-x^2}$
0.1	1.0101	0.00434	0.99005	$\bar{1}.99566$
2	1.0408	01737	96079	98263
3	1.0942	03909	91393	96091
4	1.1735	06949	85214	93051
5	1.2840	10857	77880	89143
0.6	1.4333	0.15635	0.69768	$\bar{1}.84365$
7	1.6323	21280	61263	78720
8	1.8965	27795	52729	72205
9	2.2479	35178	44486	64822
1.0	2.7183	43429	36788	56571
1.1	3.3535	0.52550	0.29820	$\bar{1}.47450$
2	4.2207	62538	23693	37462
3	5.4195	73396	18452	26604
4	7.0993	85122	14086	14878
5	9.4877	97716	10540	02284
1.6	1.2936×10	1.11179	0.77305×10^{-1}	$\bar{2}.88821$
7	1.7993 "	25511	55576 "	74489
8	2.5534 "	40711	39164 "	59289
9	3.6966 "	56780	27052 "	43220
2.0	5.4598 "	73718	18316 "	26282
2.1	8.2269 "	1.91524	0.12155 "	$\bar{2}.08476$
2	1.2647×10^2	2.10199	79071×10^{-2}	$\bar{3}.89801$
3	1.9834 "	29742	50418 "	70258
4	3.1735 "	50154	31511 "	49846
5	5.1801 "	71434	19305 "	28566
2.6	8.6264 "	2.93583	0.11592 "	$\bar{3}.06417$
7	1.4656×10^3	3.16601	68233×10^{-3}	$\bar{4}.83399$
8	2.5402 "	40487	39367 "	59513
9	4.4918 "	65242	22263 "	34758
3.0	8.1031 "	90865	12341 "	09135
3.1	1.4913×10^4	4.17357	0.67055×10^{-4}	$\bar{5}.82643$
2	2.8001 "	44718	35713 "	55282
3	5.3637 "	72947	18644 "	27053
4	1.0482×10^5	5.02044	95402×10^{-5}	$\bar{6}.97956$
5	2.0898 "	32011	47851 "	67989
3.6	4.2507 "	5.62846	0.23526 "	$\bar{6}.37154$
7	8.8205 "	94549	11337 "	05451
8	1.8673×10^6	6.27121	53553×10^{-6}	$\bar{7}.72879$
9	4.0329 "	60562	24796 "	39438
4.0	8.8861 "	94871	11254 "	05129
4.1	1.9975×10^7	7.30049	0.50062×10^{-7}	$\bar{8}.69951$
2	4.5809 "	66095	21830 "	33905
3	1.0718×10^8	8.03010	93303×10^{-8}	$\bar{9}.96990$
4	2.5582 "	40794	39089 "	59206
5	6.2296 "	79446	16052 "	20554
4.6	1.5476×10^9	9.18967	0.64614×10^{-9}	$\overline{10}.81033$
7	3.9225 "	59357	25494 "	40643
8	1.0142×10^{10}	10.00614	98595×10^{-10}	$\overline{11}.99386$
9	2.6755 "	42741	37376 "	57259
5.0	7.2005 "	85736	13888 "	14264

EXPONENTIAL FUNCTIONS

TABLE 21.—Values of $e^{\frac{\pi}{4}x}$ and $e^{-\frac{\pi}{4}x}$ and their logarithms

x	$e^{\frac{\pi}{4}x}$	$\log e^{\frac{\pi}{4}x}$	$e^{-\frac{\pi}{4}x}$	$\log e^{-\frac{\pi}{4}x}$
1	2.1933	0.34109	0.45594	$\bar{1}.65891$
2	4.8105	.68219	.20788	.31781
3	1.0551×10	1.02328	$.94780 \times 10^{-1}$	$\bar{2}.97672$
4	2.3141 "	.36438	.43214 "	.63562
5	5.0754 "	.70547	.19703 "	.29453
6	1.1132×10^{2}	2.04656	0.89833×10^{-2}	$\bar{3}.95344$
7	2.4415 "	.38766	.40958 "	.61234
8	5.3549 "	.72875	.18674 "	.27125
9	1.1745×10^{3}	3.06985	$.85144 \times 10^{-3}$	$\bar{4}.93015$
10	2.5760 "	.41094	.38820 "	.58906
11	5.6498 "	3.75203	0.17700 "	$\bar{4}.24797$
12	1.2392×10^{4}	4.09313	$.80700 \times 10^{-4}$	$\bar{5}.90687$
13	2.7178 "	.43422	.36794 "	.56578
14	5.9610 "	.77532	.16776 "	.22468
15	1.3074×10^{5}	5.11641	$.76487 \times 10^{-5}$	$\bar{6}.88359$
16	2.8675 "	5.45751	0.34873 "	$\bar{6}.54249$
17	6.2893 "	.79860	.15900 "	.20140
18	1.3794×10^{6}	6.13969	$.72495 \times 10^{-6}$	$\bar{7}.86031$
19	3.0254 "	.48079	.33053 "	.51921
20	6.6356 "	.82188	.15070 "	.17812

TABLE 22.—Values of $e^{\frac{\sqrt{\pi}}{4}x}$ and $e^{-\frac{\sqrt{\pi}}{4}x}$ and their logarithms

x	$e^{\frac{\sqrt{\pi}}{4}x}$	$\log e^{\frac{\sqrt{\pi}}{4}x}$	$e^{-\frac{\sqrt{\pi}}{4}x}$	$\log e^{-\frac{\sqrt{\pi}}{4}x}$
1	1.5576	0.19244	0.64203	$\bar{1}.80756$
2	2.4260	.38488	.41221	.61512
3	3.7786	.57733	.26465	.42267
4	5.8853	.76977	.16992	.23023
5	9.1666	.96221	.10909	.03779
6	14.277	1.15465	0.070041	$\bar{2}.84535$
7	22.238	.34709	.044968	.65291
8	34.636	.53953	.028871	.46047
9	53.948	.73198	.018536	.26802
10	84.027	.92442	.011901	.07558
11	130.88	2.11686	0.0076408	$\bar{3}.88314$
12	203.85	.30930	.0049057	.69070
13	317.50	.50174	.0031496	.49826
14	494.52	.69418	.0020222	.30582
15	770.24	.88663	.0012983	.11337
16	1199.7	3.07907	0.00083355	$\bar{4}.92093$
17	1868.6	.27151	.00053517	.72849
18	2910.4	.46395	.00034360	.53605
19	4533.1	.65639	.00022060	.34361
20	7060.5	.84883	.00014163	.15117

TABLES 23 AND 24

EXPONENTIAL FUNCTIONS AND LEAST SQUARES

EXPONENTIAL FUNCTIONS

TABLE 23.—Values of e^x and e^{-x} and their logarithms.

x	e^x	$\log e^x$	e^{-x}	x	e^x	$\log e^x$	e^{-x}
1/64	1.0157	0.00679	0.98450	1/3	1.3956	0.14476	0.71653
1/32	.0317	.01357	.96923	1/2	.6487	.21715	.60653
1/16	.0645	.02714	.93941	3/4	2.1170	.32572	.47237
1/10	.1052	.04343	.90484	1	.7183	.43429	.36788
1/9	.1175	.04825	.89484	5/4	3.4903	.54287	.28650
1/8	1.1331	0.05429	0.88250	3/2	4.4817	0.65144	0.22313
1/7	.1536	.06204	.86688	7/4	5.7546	.76002	.17377
1/6	.1814	.07238	.84648	2	7.3891	.86859	.13534
1/5	.2214	.08686	.81873	9/4	9.4877	.97716	.10540
1/4	.2840	.10857	.77880	5/2	12.1825	1.08574	.08208

LEAST SQUARES

TABLE 24.—Values of $P = \frac{2}{\sqrt{\pi}}\int_0^{hx} e^{-(hx)^2}\, d(hx)$.

P, the probability of an observational error having a value positive or negative equal to or less than x when h is the measure of precision, $P = \frac{2}{\sqrt{\pi}}\int_0^{hx} e^{-(hx)^2} d(hx)$. $h^2 = (\frac{1}{2} m \Delta x^2)$ where m = no. obs. of deviation Δx.

hx	0	1	2	3	4	5	6	7	8	9
0.0		.01128	.02256	.03384	.04511	.05637	.06762	.07886	.09008	.10128
.1	.11246	.12362	.13476	.14587	.15695	.16800	.17901	.18999	.20094	.21184
.2	.22270	.23352	.24430	.25502	.26570	.27633	.28690	.29742	.30788	.31828
.3	.32863	.33891	.34913	.35928	.36936	.37938	.38933	.39921	.40901	.41874
.4	.42839	.43797	.44747	.45689	.46623	.47548	.48466	.49375	.50275	.51167
0.5	.52050	.52924	.53790	.54646	.55494	.56332	.57162	.57982	.58792	.59594
.6	.60386	.61168	.61941	.62705	.63459	.64203	.64938	.65663	.66378	.67084
.7	.67780	.68467	.69143	.69810	.70468	.71116	.71754	.72382	.73001	.73610
.8	.74210	.74800	.75381	.75952	.76514	.77067	.77610	.78144	.78669	.79184
.9	.79691	.80188	.80677	.81156	.81627	.82089	.82542	.82987	.83423	.83851
1.0	.84270	.84681	.85084	.85478	.85865	.86244	.86614	.86977	.87333	.87680
.1	.88021	.88353	.88679	.88997	.89308	.89612	.89910	.90200	.90484	.90761
.2	.91031	.91296	.91553	.91805	.92051	.92290	.92524	.92751	.92973	.93190
.3	.93401	.93606	.93807	.94002	.94191	.94376	.94556	.94731	.94902	.95067
.4	.95229	.95385	.95538	.95686	.95830	.95970	.96105	.96237	.96365	.96490
1.5	.96611	.96728	.96841	.96952	.97059	.97162	.97263	.97360	.97455	.97546
.6	.97635	.97721	.97804	.97884	.97962	.98038	.98110	.98181	.98249	.98315
.7	.98379	.98441	.98500	.98558	.98613	.98667	.98719	.98769	.98817	.98864
.8	.98909	.98952	.98994	.99035	.99074	.99111	.99147	.99182	.99216	.99248
.9	.99279	.99309	.99338	.99366	.99392	.99418	.99443	.99466	.99489	.99511
2.0	.99532	.99552	.99572	.99591	.99609	.99626	.99642	.99658	.99673	.99688
.1	.99702	.99715	.99728	.99741	.99753	.99764	.99775	.99785	.99795	.99805
.2	.99814	.99822	.99831	.99839	.99846	.99854	.99861	.99867	.99874	.99880
.3	.99886	.99891	.99897	.99902	.99906	.99911	.99915	.99920	.99924	.99928
.4	.99931	.99935	.99938	.99941	.99944	.99947	.99950	.99952	.99955	.99957
2.5	.99959	.99961	.99963	.99965	.99967	.99969	.99971	.99972	.99974	.99975
.6	.99976	.99978	.99979	.99980	.99981	.99982	.99983	.99984	.99985	.99986
.7	.99987	.99987	.99988	.99989	.99989	.99990	.99991	.99991	.99992	.99992
.8	.99992	.99993	.99993	.99994	.99994	.99994	.99995	.99995	.99995	.99996
.9	.99996	.99996	.99996	.99997	.99997	.99997	.99997	.99997	.99997	.99998
3.0	.99998	.99999	.99999	1.00000						

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Tables 25 and 26

LEAST SQUARES

TABLE 25

This table gives the values of the probability P, as defined in last table, corresponding to different values of x/r where r is the "probable error." The probable error r is equal to $0.47694/h$.

$\frac{x}{r}$	0	1	2	3	4	5	6	7	8	9
0.0	.00000	.00538	.01076	.01614	.02152	.02690	.03228	.03766	.04303	.04840
0.1	.05378	.05914	.06451	.06987	.07523	.08059	.08594	.09129	.09663	.10197
0.2	.10731	.11264	.11796	.12328	.12860	.13391	.13921	.14451	.14980	.15508
0.3	.16035	.16562	.17088	.17614	.18138	.18662	.19185	.19707	.20229	.20749
0.4	.21268	.21787	.22304	.22821	.23336	.23851	.24364	.24876	.25388	.25898
0.5	.26407	.26915	.27421	.27927	.28431	.28934	.29436	.29936	.30435	.30933
0.6	.31430	.31925	.32419	.32911	.33402	.33892	.34380	.34866	.35352	.35835
0.7	.36317	.36798	.37277	.37755	.38231	.38705	.39178	.39649	.40118	.40586
0.8	.41052	.41517	.41979	.42440	.42899	.43357	.43813	.44267	.44719	.45169
0.9	.45618	.46064	.46509	.46952	.47393	.47832	.48270	.48705	.49139	.49570
1.0	.50000	.50428	.50853	.51277	.51699	.52119	.52537	.52952	.53366	.53778
1.1	.54188	.54595	.55001	.55404	.55806	.56205	.56602	.56998	.57391	.57782
1.2	.58171	.58558	.58942	.59325	.59705	.60083	.60460	.60833	.61205	.61575
1.3	.61942	.62308	.62671	.63032	.63391	.63747	.64102	.64454	.64804	.65152
1.4	.65498	.65841	.66182	.66521	.66858	.67193	.67526	.67856	.68184	.68510
1.5	.68833	.69155	.69474	.69791	.70106	.70419	.70729	.71038	.71344	.71648
1.6	.71949	.72249	.72546	.72841	.73134	.73425	.73714	.74000	.74285	.74567
1.7	.74847	.75124	.75400	.75674	.75945	.76214	.76481	.76746	.77009	.77270
1.8	.77528	.77785	.78039	.78291	.78542	.78790	.79036	.79280	.79522	.79761
1.9	.79999	.80235	.80469	.80700	.80930	.81158	.81383	.81607	.81828	.82048
2.0	.82266	.82481	.82695	.82907	.83117	.83324	.83530	.83734	.83936	.84137
2.1	.84335	.84531	.84726	.84919	.85109	.85298	.85486	.85671	.85854	.86036
2.2	.86216	.86394	.86570	.86745	.86917	.87088	.87258	.87425	.87591	.87755
2.3	.87918	.88078	.88237	.88395	.88550	.88705	.88857	.89008	.89157	.89304
2.4	.89450	.89595	.89738	.89879	.90019	.90157	.90293	.90428	.90562	.90694
2.5	.90825	.90954	.91082	.91208	.91332	.91456	.91578	.91698	.91817	.91935
2.6	.92051	.92166	.92280	.92392	.92503	.92613	.92721	.92828	.92934	.93038
2.7	.93141	.93243	.93344	.93443	.93541	.93638	.93734	.93828	.93922	.94014
2.8	.94105	.94195	.94284	.94371	.94458	.94543	.94627	.94711	.94793	.94874
2.9	.94954	.95033	.95111	.95187	.95263	.95338	.95412	.95484	.95557	.95628
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
3	.95698	.96346	.96910	.97397	.97817	.98176	.98482	.98743	.98962	.99147
4	.99302	.99431	.99539	99627	.99700	.99760	.99808	.99848	.99879	.99905
5	.99926	.99943	.99956	.99966	.99974	.99980	.99985	.99988	.99991	.99993

TABLE 26.—Values of the factor $0.6745\sqrt{\frac{1}{n-1}}$.

This factor occurs in the equation $r_s = 0.6745\sqrt{\frac{\Sigma v^2}{n-1}}$ for the probable error of a single observation, and other similar equations.

n	0	1	2	3	4	5	6	7	8	9
00			0.6745	0.4769	0.3894	0.3372	0.3016	0.2754	0.2549	0.2385
10	0.2248	0.2133	.2034	.1947	.1871	.1803	.1742	.1686	.1636	.1590
20	.1547	.1508	.1472	.1438	.1406	.1377	.1349	.1323	.1298	.1275
30	.1252	.1231	.1211	.1192	.1174	.1157	.1140	.1124	.1109	.1094
40	.1080	.1066	.1053	.1041	.1029	.1017	.1005	.0994	.0984	.0974
50	0.0964	0.0954	0.0944	0.0935	0.0926	0.0918	0.0909	0.0901	0.0893	0.0886
60	.0878	.0871	.0864	.0857	.0850	.0843	.0837	.0830	.0824	.0818
70	.0812	.0806	.0800	.0795	.0789	.0784	.0779	.0774	.0769	.0764
80	.0759	.0754	.0749	.0745	.0740	.0736	.0732	.0727	.0723	.0719
90	.0715	.0711	.0707	.0703	.0699	.0696	.0692	.0688	.0685	.0681

LEAST SQUARES

TABLE 27.—Values of the factor $0.6745\sqrt{\frac{1}{n(n-1)}}$

This factor occurs in the equation $r_0=0.6745\sqrt{\frac{\Sigma v^2}{n(n-1)}}$ for the probable error of the arithmetical mean.

n =		1	2	3	4	5	6	7	8	9
00			0.4769	0.2754	0.1947	0.1508	0.1231	0.1041	0.0901	0.0795
10	0.0711	0.0643	.0587	.0540	.0500	.0465	.0435	.0409	.0386	.0365
20	.0346	.0329	.0314	.0300	.0287	.0275	.0265	.0255	.0245	.0237
30	.0229	.0221	.0214	.0208	.0201	.0196	.0190	.0185	.0180	.0175
40	.0171	.0167	.0163	.0159	.0155	.0152	.0148	.0145	.0142	.0139
50	0.0136	0.0134	0.0131	0.0128	0.0126	0.0124	0.0122	0.0119	0.0117	0.0115
60	.0113	.0111	.0110	.0108	.0106	.0105	.0103	.0101	.0100	.0098
70	.0097	.0096	.0094	.0093	.0092	.0091	.0089	.0088	.0087	.0086
80	.0085	.0084	.0083	.0082	.0081	.0080	.0079	.0078	.0077	.0076
90	.0075	.0075	.0074	.0073	.0072	.0071	.0071	.0070	.0069	.0068

TABLE 28.—Values of the factor $0.8453\sqrt{\frac{1}{n(n-1)}}$

This factor occurs in the approximate equation $r=0.8453\frac{\Sigma|v|}{\sqrt{n(n-1)}}$ for the probable error of a single observation.

n =		1	2	3	4	5	6	7	8	9
00			0.5978	0.3451	0.2440	0.1890	0.1543	0.1304	0.1130	0.0996
10	0.0891	0.0806	.0736	.0677	.0627	.0583	.0546	.0513	.0483	.0457
20	.0434	.0412	.0393	.0376	.0360	.0345	.0332	.0319	.0307	.0297
30	.0287	.0277	.0268	.0260	.0252	.0245	.0238	.0232	.0225	.0220
40	.0214	.0209	.0204	.0199	.0194	.0190	.0186	.0182	.0178	.0174
50	0.0171	0.0167	0.0164	0.0161	0.0158	0.0155	0.0152	0.0150	0.0147	0.0145
60	.0142	.0140	.0137	.0135	.0133	.0131	.0129	.0127	.0125	.0123
70	.0122	.0120	.0118	.0117	.0115	.0113	.0112	.0111	.0109	.0108
80	.0106	.0105	.0104	.0102	.0101	.0100	.0099	.0098	.0097	.0096
90	.0094	.0093	.0092	.0091	.0090	.0089	.0089	.0088	.0087	.0086

TABLE 29.—Values of $0.8453\frac{1}{n\sqrt{n-1}}$

This factor occurs in the approximate equation $r_0=0.8453\frac{\Sigma|v|}{n\sqrt{n-1}}$ for the probable error of the arithmetical mean.

n =		1	2	3	4	5	6	7	8	9
00			0.4227	0.1993	0.1220	0.0845	0.0630	0.0493	0.0399	0.0332
10	0.0282	0.0243	.0212	.0188	.0167	.0151	.0136	.0124	.0114	.0105
20	.0097	.0090	.0084	.0078	.0073	.0069	.0065	.0061	.0058	.0055
30	.0052	.0050	.0047	.0045	.0043	.0041	.0040	.0038	.0037	.0035
40	.0034	.0033	.0031	.0030	.0029	.0028	.0027	.0027	.0026	.0025
50	0.0024	0.0023	0.0023	0.0022	0.0022	0.0021	0.0020	0.0020	0.0019	0.0019
60	.0018	.0018	.0017	.0017	.0017	.0016	.0016	.0016	.0015	.0015
70	.0015	.0014	.0014	.0014	.0013	.0013	.0013	.0013	.0012	.0012
80	.0012	.0012	.0011	.0011	.0011	.0011	.0011	.0010	.0010	.0010
90	.0010	.0010	.0010	.0009	.0009	.0009	.0009	.0009	.0009	.0009

TABLE 30
LEAST SQUARES (FORMULAE)

Observation equations:

$$a_1z_1 + b_1z_2 + \ldots l_1z_q = M_1, \text{ weight } p_1$$
$$a_2z_1 + b_2z_2 + \ldots l_2z_q = M_2. \text{ weight } p_2$$
$$\cdots$$
$$a_nz_1 + b_nz_2 + \ldots l_nz_q = M_n, \text{ weight } p_n.$$

Auxiliary equations:

$$[paa] = p_1a_1^2 + p_2a_2^2 + \ldots p_na_n^2.$$
$$[pab] = p_1a_1b_1 + p_2a_2b_2 + \ldots p_na_nb_n.$$
$$\cdots$$
$$[paM] = p_1a_1M_1 + p_2a_2M_2 + \ldots p_na_nM_n.$$

Normal equations:

$$[paa]z_1 + [pab]z_2 + \ldots [pal]z_q = [paM]$$
$$[pab]z_1 + [pbb]z_2 + \ldots [pbl]z_q = [pbM]$$
$$\cdots$$
$$[pla]z_1 + [plb]z_2 + \ldots [pll]z_q = [plM].$$

Solution of normal equations in the form,

$$z_1 = A_1[paM] + B_1[pbM] + \ldots L_1[plM]$$
$$z_2 = A_2[paM] + B_2[pbM] + \ldots L_2[plM]$$
$$\cdots$$
$$z_q = A_n[paM] + B_n[pbM] + \ldots L_n[plM],$$

gives:

$$\text{weight of } z_1 = p_{z_1} = (A_1)^{-1}; \text{ probable error of } z_1 = \frac{r}{\sqrt{p_{z_1}}}$$
$$\text{weight of } z_2 = p_{z_2} = (B_2)^{-1}; \text{ probable error of } z_2 = \frac{r}{\sqrt{p_{z_2}}}$$
$$\cdots$$
$$\text{weight of } z_q = p_{z_q} = (L_n)^{-1}; \text{ probable error of } z_q = \frac{r}{\sqrt{p_{z_q}}}$$

wherein

$$r = \text{probable error of observation of weight unity}$$
$$= 0.6745\sqrt{\frac{\Sigma pv^2}{n-q}}. \text{ (q unknowns.)}$$

Arithmetical mean, n observations:

$$r = 0.6745\sqrt{\frac{\Sigma v^2}{n-1}} = \frac{0.8453\,\Sigma v}{\sqrt{n(n-1)}}.$$ (approx.) = probable error of observation of weight unity.

$$r_0 = 0.6745\sqrt{\frac{\Sigma v^2}{n(n-1)}} = \frac{0.8453\,\Sigma v}{n\sqrt{n-1}}.$$ (approx.) = probable error of mean.

Weighted mean, n observations:

$$r = 0.6745\sqrt{\frac{\Sigma pv^2}{n-1}};\quad r_0 = \frac{r}{\sqrt{\Sigma p}} = 0.6745\sqrt{\frac{\Sigma pv^2}{(n-1)\Sigma p}}$$

Probable error (R) of a function (Z) of several observed quantities $z_1, z_2, \ldots$ whose probable errors are respectively, $r_1, r_2, \ldots$.

$$Z = f(z_1, z_2, \ldots)$$
$$R^2 = \left(\frac{\partial Z}{\partial z_1}\right)^2 r_1^2 + \left(\frac{\partial Z}{\partial z_2}\right)^2 r_2^2 + \ldots$$

Examples:

$$Z = z_1 \pm z_2 + \ldots \qquad R^2 = r_1^2 + r_2^2 + \ldots$$
$$Z = Az_1 \pm Bz_2 \pm \ldots \qquad R^2 = A^2r_1^2 + B^2r_2^2 + \ldots$$
$$Z = z_1 z_2. \qquad R^2 = z_1^2 r_2^2 + z_2^2 r_1^2.$$

See Birge, Calculation of errors by the method of least squares, Phys. Rev., 40, 207, 1932.

TABLE 31

DIFFUSION INTEGRAL

Inverse * values of $v/c = 1 - \frac{2}{\sqrt{\pi}} \int_0^q e^{-q^2} dq$

$\log x = \log (2q) + \log \sqrt{kt}$. t expressed in seconds.
$= \log \delta + \log \sqrt{kt}$. t expressed in days.
$= \log \gamma + \log \sqrt{kt}$. " " years.
k = coefficient of diffusion.†
c = initial concentration.
v = concentration at distance x, time t.

v/c	$\log 2q$	$2q$	$\log \delta$	δ	$\log \gamma$	γ
0.00	$+\infty$	$+\infty$	$+\infty$	$+\infty$	∞	∞
.01	0.56143	3.6428	3.02970	1070.78	4.31098	20463.
.02	.51719	3.2900	2.98545	967.04	.26674	18481.
.03	.48699	3.0690	.95525	902.90	.23654	17240.
.04	.46306	2.9044	.93132	853.73	.21261	16316.
0.05	0.44276	2.7718	2.91102	814.74	4.19231	15571.
.06	.42486	2.6598	.89311	781.83	.17440	14942.
.07	.40865	2.5624	.87691	753.20	.15820	14395.
.08	.39372	2.4758	.86198	727.75	.14327	13908.
.09	.37979	2.3977	.84804	704.76	.12933	13469.
0.10	0.36664	2.3262	2.83490	683.75	4.11619	13067.
.11	.35414	2.2602	.82240	664.36	.10369	12697.
.12	.34218	2.1988	.81044	646.31	.09173	12352.
.13	.33067	2.1413	.79893	629.40	.08022	12029.
.14	.31954	2.0871	.78780	613.47	.06909	11724.
0.15	0.30874	2.0358	2.77699	598.40	4.05828	11436.
.16	.29821	1.9871	.76647	584.08	.04776	11162.
.17	.28793	1.9406	.75619	570.41	.03748	10901.
.18	.27786	1.8961	.74612	557.34	.02741	10652.
.19	.26798	1.8534	.73624	544.80	.01753	10412.
0.20	0.25825	1.8124	2.72651	532.73	4.00780	10181.
.21	.24866	1.7728	.71692	521.10	3.99821	9958.9
.22	.23919	1.7346	.70745	509.86	.98874	9744.1
.23	.22983	1.6976	.69808	498.98	.97937	9536.2
.24	.22055	1.6617	.68880	488.43	.97010	9334.6
0.25	0.21134	1.6268	2.67960	478.19	3.96089	9138.9
.26	.20220	1.5930	.67046	468.23	.95175	8948.5
.27	.19312	1.5600	.66137	458.53	.94266	8763.2
.28	.18407	1.5278	.65232	449.08	.93361	8582.5
.29	.17505	1.4964	.64331	439.85	.92460	8406.2
0.30	0.16606	1.4657	2.63431	430.84	3.91560	8233.9
.31	.15708	1.4357	.62533	422.02	.90662	8065.4
.32	.14810	1.4064	.61636	413.39	.89765	7900.4
.33	.13912	1.3776	.60738	404.93	.88867	7738.8
.34	.13014	1.3494	.59840	396.64	.87969	7580.3
0.35	0.12114	1.3217	2.58939	388.50	3.87068	7424.8
.36	.11211	1.2945	.58037	380.51	.86166	7272.0
.37	.10305	1.2678	.57131	372.66	.85260	7122.0
.38	.09396	1.2415	.56222	364.93	.84351	6974.4
.39	.08482	1.2157	.55308	357.34	.83437	6829.2
0.40	0.07563	1.1902	2.54389	349.86	3.82518	6686.2
.41	.06639	1.1652	.53464	342.49	.81593	6545.4
.42	.05708	1.1405	.52533	335.22	.80662	6406.6
.43	.04770	1.1161	.51595	328.06	.79724	6269.7
.44	.03824	1.0920	.50650	320.99	.78779	6134.6
0.45	0.02870	1.0683	2.49696	314.02	3.77825	6001.3
.46	.01907	1.0449	.48733	307.13	.76862	5869.7
.47	.00934	1.0217	.47760	300.33	.75889	5739.7
.48	9.99951	0.99886	.46776	293.60	.74905	5611.2
.49	.98956	0.97624	.45782	286.96	.73911	5484.1
0.50	9.97949	0.95387	2.44775	280.38	3.72904	5358.4

† Kelvin, Mathematical and Physical Papers, vol. III. p. 428; Becker, Am. Jour. of Sci. vol. III. 1897, p. 280.

* For direct values see table 24.

DIFFUSION INTEGRAL

v/c	log $2q$	$2q$	log δ	δ	log γ	γ
0.50	9.97949	0.95387	2.44775	280.38	3.72904	5358.4
.51	.96929	.93174	.43755	273.87	.71884	5234.1
.52	.95896	.90983	.42722	267.43	.70851	5111.0
.53	.94848	.88813	.41674	261.06	.69803	4989.1
.54	.93784	.86665	.40610	254.74	.68739	4868.4
0.55	9.92704	0.84536	2.39530	248.48	3.67659	4748.9
.56	.91607	.82426	.38432	242.28	.66561	4630.3
.57	.90490	.80335	.37316	236.13	.65445	4512.8
.58	.89354	.78260	.36180	230.04	.64309	4396.3
.59	.88197	.76203	.35023	223.99	.63152	4280.7
0.60	9.87018	0.74161	2.33843	217.99	3.61973	4166.1
.61	.85815	.72135	.32640	212.03	.60770	4052.2
.62	.84587	.70124	.31412	206.12	.59541	3939.2
.63	.83332	.68126	.30157	200.25	.58286	3827.0
.64	.82048	.66143	.28874	194.42	.57003	3715.6
0.65	9.80734	0.64172	2.27560	188.63	3.55689	3604.9
.66	.79388	.62213	.26214	182.87	.54343	3494.9
.67	.78008	.60266	.24833	177.15	.52962	3385.4
.68	.76590	.58331	.23416	171.46	.51545	3276.8
.69	.75133	.56407	.21959	165.80	.50088	3168.7
0.70	9.73634	0.54493	2.20459	160.17	3.48588	3061.1
.71	.72089	.52588	.18915	154.58	.47044	2954.2
.72	.70495	.50694	.17321	149.01	.45450	2847.7
.73	.68849	.48808	.15675	143.47	.43804	2741.8
.74	.67146	.46931	.13972	137.95	.42101	2636.4
0.75	9.65381	0.45062	2.12207	132.46	3.40336	2531.4
.76	.63550	.43202	.10376	126.99	.38505	2426.9
.77	.61646	.41348	.08471	121.54	.36600	2322.7
.78	.59662	.39502	.06487	116.11	.34616	2219.0
.79	.57590	.37662	.04416	110.70	.32545	2115.7
0.80	9.55423	0.35829	2.02249	105.31	3.30378	2012.7
.81	.53150	.34001	1.99975	99.943	.28104	1910.0
.82	.50758	.32180	.97584	94.589	.25713	1807.7
.83	.48235	.30363	.95061	89.250	.23190	1705.7
.84	.45564	.28552	.92389	83.926	.20518	1603.9
0.85	9.42725	0.26745	1.89551	78.615	3.17680	1502.4
.86	.39695	.24943	.86521	73.317	.14650	1401.2
.87	.36445	.23145	.83271	68.032	.11400	1300.2
.88	.32940	.21350	.79766	62.757	.07895	1199.4
.89	.29135	.19559	.75961	57.492	3.04090	1098.7
0.90	9.24972	0.17771	1.71797	52.236	2.99926	998.31
.91	.20374	.15986	.67200	46.989	.95329	898.03
.92	.15239	.14203	.62065	41.750	.90194	797.89
.93	.09423	.12423	.56249	36.516	.84378	697.88
.94	9.02714	.10645	.49539	31.289	.77668	597.98
0.95	8.94783	0.08868	1.41609	26.067	2.69738	498.17
.96	.85082	.07093	.31907	20.848	.60036	398.44
.97	.72580	.05319	.19406	15.633	.47535	298.78
.98	.54965	.03545	.01791	10.421	.29920	199.16
.99	.24859	.01773	0.71684	5.21007	1.99813	99.571
1.00	$-\infty$	0.00000	$-\infty$	0.00000	$-\infty$	0.000

Table 32

VALUES OF THE EXPONENTIAL INTEGRAL

$$Ei(x) = \int_{\infty}^{-x} (e^{-u}/u)du$$

x	Ei(x)	Ei(−x)	x	Ei(x)	Ei(−x)
0.00	− ∞	− ∞	0.50	+0.454 220	−0.559 774
.01	−4.017 929	−4.037 930	.51	0.487 032	−0.547 822
.02	−3.314 707	−3.354 708	.52	0.519 531	−0.536 220
.03	−2.899 116	−2.959 119	.53	0.551 730	−0.524 952
.04	−2.601 257	−2.681 264	.54	0.583 646	−0.514 004
0.05	−2.367 885	−2.467 898	0.55	+0.615 291	−0.503 364
.06	−2.175 283	−2.295 307	.56	0.646 677	−0.493 020
.07	−2.010 800	−2.150 838	.57	0.677 819	−0.482 960
.08	−1.866 884	−2.026 941	.58	0.708 726	−0.473 173
.09	−1.738 664	−1.918 745	.59	0.739 410	−0.463 650
0.10	−1.622 813	−1.822 924	0.60	+0.769 881	−0.454 380
.11	−1.516 959	−1.737 107	.61	0.800 150	−0.445 353
.12	−1.419 350	−1.659 542	.62	0.830 226	−0.436 562
.13	−1.328 655	−1.588 899	.63	0.860 119	−0.427 997
.14	−1.243 841	−1.524 146	.64	0.889 836	−0.419 652
0.15	−1.164 086	−1.464 462	0.65	+0.919 386	−0.411 517
.16	−1.088 731	−1.409 187	.66	0.948 778	−0.403 586
.17	−1.017 234	−1.357 781	.67	0.978 019	−0.395 853
.18	−0.949 148	−1.309 796	.68	1.007 116	−0.388 309
.19	−0.884 095	−1.264 858	.69	1.036 077	−0.380 950
0.20	−0.821 761	−1.222 651	0.70	+1.064 907	−0.373 769
.21	−0.761 872	−1.182 902	.71	1.093 615	−0.366 760
.22	−0.704 195	−1.145 380	.72	1.122 205	−0.359 918
.23	−0.648 529	−1.109 883	.73	1.150 684	−0.353 237
.24	−0.594 697	−1.076 235	.74	1.179 058	−0.346 713
0.25	−0.542 543	−1.044 283	0.75	+1.207 333	−0.340 341
.26	−0.491 932	−1.013 889	.76	1.235 513	−0.334 115
.27	−0.442 741	−0.984 933	.77	1.263 605	−0.328 032
.28	−0.394 863	−0.957 308	.78	1.291 613	−0.322 088
.29	−0.348 202	−0.930 918	.79	1.319 542	−0.316 277
0.30	−0.302 669	−0.905 677	0.80	+1.347 397	−0.310 597
.31	−0.258 186	−0.881 506	.81	1.375 182	−0.305 043
.32	−0.214 683	−0.858 335	.82	1.402 902	−0.299 611
.33	−0.172 095	−0.836 101	.83	1.430 561	−0.294 299
.34	−0.130 363	−0.814 746	.84	1.458 164	−0.289 103
0.35	−0.089 434	−0.794 215	0.85	+1.485 714	−0.284 019
.36	−0.049 258	−0.774 462	.86	1.513 216	−0.279 045
.37	−0.009 790	−0.755 441	.87	1.540 673	−0.274 177
.38	+0.029 011	−0.737 112	.88	1.568 089	−0.269 413
.39	+0.067 185	−0.719 437	.89	1.595 467	−0.264 749
0.40	+0.104 765	−0.702 380	0.90	+1.622 812	−0.260 184
.41	+0.141 786	−0.685 910	.91	1.650 126	−0.255 714
.42	+0.178 278	−0.669 997	.92	1.677 413	−0.251 336
.43	+0.214 270	−0.654 613	.93	1.704 677	−0.247 050
.44	+0.249 787	−0.639 733	.94	1.731 920	−0.242 851
0.45	+0.284 855	−0.625 331	0.95	+1.759 146	−0.238 738
.46	0.319 497	−0.611 387	.96	1.786 357	−0.234 708
.47	0.353 735	−0.597 877	.97	1.813 557	−0.230 760
.48	0.387 589	−0.584 784	.98	1.840 749	−0.226 891
.49	0.421 078	−0.572 089	.99	1.867 935	−0.223 100
0.50	+0.454 220	−0.559 774	1.00	+1.895 118	−0.219 384

(Taken from Glaisher, Philos. Trans., 160, 367, 1870)

TABLE 32 (*continued*)

VALUES OF EXPONENTIAL INTEGRAL

$$Ei(x) = \int_{\infty}^{-x} (e^{-u}/u)du$$

x	Ei(x)	Ei—(x)	x	Ei(x)	Ei—(x)
1.0	+1.895 118	−0.219 384	3.0	+ 9.933 833	−0.013 0484
1.1	2.167 378	−0.185 991	3.1	10.626 300	−0.011 4944
1.2	2.442 092	−0.158 408	3.2	11.367 303	−0.010 1330
1.3	2.721 399	−0.135 451	3.3	12.161 041	−0.008 9390
1.4	3.007 207	−0.116 219	3.4	13.012 075	−0.007 8910
1.5	+3.301 285	−0.100 020	3.5	+13.925 354	−0.006 9701
1.6	3.605 320	−0.086 3083	3.6	14.906 254	−0.006 1604
1.7	3.920 963	−0.074 6546	3.7	15.960 619	−0.005 4478
1.8	4.249 868	−0.064 7131	3.8	17.094 802	−0.004 8202
1.9	4.593 714	−0.056 2044	3.9	18.315 714	−0.004 2671
2.0	+4.954 234	−0.048 9005	4.0	+19.630 874	−0.003 7794
2.1	5.333 235	−0.042 6143	4.1	21.048 467	−0.003 3489
2.2	5.732 615	−0.037 1911	4.2	22.577 401	−0.002 9688
2.3	6.154 381	−0.032 5023	4.3	24.227 380	−0.002 6329
2.4	6.600 670	−0.028 4403	4.4	26.008 973	−0.002 3360
2.5	+7.073 766	−0.024 9149	4.5	+27.933 697	−0.002 0734
2.6	7.576 115	−0.021 8502	4.6	30.014 099	−0.001 8410
2.7	8.110 347	−0.019 1819	4.7	32.263 860	−0.001 6352
2.8	8.679 298	−0.016 8553	4.8	34.697 890	−0.001 4530
2.9	9.286 024	−0.014 8240	4.9	37.332 451	−0.001 2915
3.0	+9.933 833	−0.013 0484	5.0	+40.185 275	−0.001 1483

x	Ei(x)	Ei(—x)
6	+ 85.989 762	− 0.000 360 082
7	+ 191.504 743	− .000 115 482
8	+ 440.379 900	− .000 037 665 6
9	+ 1037.878 291	− .000 012 447 4
10	+ 2492.228 976	− .000 004 156 97
11	+ 6071.406 374	− .000 001 400 30
12	+ 14959.532 666	− .000 000 475 11
13	+ 37197.688 491	− .000 000 162 19
14	+ 93192.513 634	− .000 000 055 66
15	+ 234955.852 491	− .000 000 019 18

(Taken from Glaisher, Philos. Trans., 160, 367, 1870)

Table 33

GAMMA FUNCTION *

Value of $\log \int_0^{\infty} e^{-x} x^{n-1} dx + 10$

Values of the logarithms + 10 of the "Second Eulerian Integral" (Gamma function) $\int_0^{\infty} e^{-x} x^{n-1} dx = \log \Gamma(n) + 10$ for values of n between 1 and 2. When n has values not lying between 1 and 2 the value of the function can be readily calculated from the equation $\Gamma(n+1) = n\Gamma(n) = n(n-1) \ldots (n-r)\Gamma(n-r)$.

n	0	1	2	3	4	5	6	7	8	9
1.00	9.99———	97497	95001	92512	90030	87555	85087	82627	80173	77727
1.01	75287	72855	70430	68011	65600	63196	60798	58408	56025	53648
1.02	51279	48916	46561	44212	41870	39535	37207	34886	32572	30265
1.03	27964	25671	23384	21104	18831	16564	14305	12052	09806	07567
1.04	05334	03108	00889	98677	96471	94273	92080	89895	87716	85544
1.05	9.9883379	81220	79068	76922	74783	72651	70525	68406	66294	64188
1.06	62089	59996	57910	55830	53757	51690	49630	47577	45530	43489
1.07	41455	39428	37407	35392	33384	31382	29387	27398	25415	23439
1.08	21469	19506	17549	15599	13655	11717	09785	07860	05941	04029
1.09	02123	00223	98329	96442	94561	92686	90818	88956	87100	85250
1.10	9.9783407	81570	79738	77914	76095	74283	72476	70676	68882	67095
1.11	65313	63538	61768	60005	58248	56497	54753	53014	51281	49555
1.12	47834	46120	44411	42709	41013	39323	37638	35960	34288	32622
1.13	30962	29308	27659	26017	24381	22751	21126	19508	17896	16289
1.14	14689	13094	11505	09922	08345	06774	05209	03650	02096	00549
1.15	9.9699007	97471	95941	94417	92898	91386	89879	88378	86883	85393
1.16	83910	82432	80960	79493	78033	76578	75129	73686	72248	70816
1.17	69390	67969	66554	65145	63742	62344	60952	59566	58185	56810
1.18	55440	54076	52718	51366	50019	48677	47341	46011	44687	43368
1.19	42054	40746	39444	38147	36856	35570	34290	33016	31747	30483
1.20	9.9629225	27973	26725	25484	24248	23017	21792	20573	19358	18150
1.21	16946	15748	14556	13369	12188	11011	09841	08675	07515	06361
1.22	05212	04068	02930	01796	00669	99546	98430	97318	96212	95111
1.23	594015	92925	91840	90760	89685	88616	87553	86494	85441	84393
1.24	83350	82313	81280	80253	79232	78215	77204	76198	75197	74201
1.25	9.9573211	72226	71246	70271	69301	68337	67377	66423	65474	64530
1.26	63592	62658	61730	60806	59888	58975	58067	57165	56267	55374
1.27	54487	53604	52727	51855	50988	50126	49268	48416	47570	46728
1.28	45891	45059	44232	43410	42593	41782	40975	40173	39376	38585
1.29	37798	37016	36239	35467	34700	33938	33181	32429	31682	30940
1.30	9.9530203	29470	28743	28021	27303	26590	25883	25180	24482	23789
1.31	23100	22417	21739	21065	20396	19732	19073	18419	17770	17125
1.32	16485	15850	15220	14595	13975	13359	12748	12142	11541	10944
1.33	10353	09766	09184	08606	08034	07466	06903	06344	05791	05242
1.34	04698	04158	03624	03094	02568	02048	01532	01021	00514	00012
1.35	9.9499515	99023	98535	98052	97573	97100	96630	96166	95706	95251
1.36	94800	94355	93913	93477	93044	92617	92194	91776	91362	90953
1.37	90549	90149	89754	89363	88977	88595	88218	87846	87478	87115
1.38	86756	86402	86052	85707	85366	85030	84698	84371	84049	83731
1.39	83417	83108	82803	82503	82208	81916	81630	81348	81070	80797
1.40	9.9480528	80263	80003	79748	79497	79250	79008	78770	78537	78308
1.41	78084	77864	77648	77437	77230	77027	76829	76636	76446	76261
1.42	76081	75905	75733	75565	75402	75243	75089	74939	74793	74652
1.43	74515	74382	74254	74130	74010	73894	73783	73676	73574	73476
1.44	73382	73292	73207	73125	73049	72976	72908	72844	72784	72728

* Legendre's "Exercises de Calcul Intégral," tome ii.

GAMMA FUNCTION

n	0	1	2	3	4	5	6	7	8	9
1.45	9.9472677	72630	72587	72549	72514	72484	72459	72437	72419	72406
1.46	72397	72393	72392	72396	72404	72416	72432	72452	72477	72506
1.47	72539	72576	72617	72662	72712	72766	72824	72886	72952	73022
1.48	73097	73175	73258	73345	73436	73531	73630	73734	73841	73953
1.49	74068	74188	74312	74440	74572	74708	74848	74992	75141	75293
1.50	9.9475449	75610	75774	75943	76116	76292	76473	76658	76847	77040
1.51	77237	77437	77642	77851	78064	78281	78502	78727	78956	79189
1.52	79426	79667	79912	80161	80414	80671	80932	81196	81465	81738
1.53	82015	82295	82580	82868	83161	83457	83758	84062	84370	84682
1.54	84998	85318	85642	85970	86302	86638	86977	87321	87668	88019
1.55	9.9488374	88733	89096	89463	89834	90208	90587	90969	91355	91745
1.56	92139	92537	92938	93344	93753	94166	94583	95004	95429	95857
1.57	96289	96725	97165	97609	98056	98508	98963	99422	99885	00351
1.58	500822	01296	01774	02255	02741	03230	03723	04220	04720	05225
1.59	05733	06245	06760	07280	07803	08330	08860	09395	09933	10475
1.60	9.9511020	11569	12122	12679	13240	13804	14372	14943	15519	16098
1.61	16680	17267	17857	18451	19048	19649	20254	20862	21475	22091
1.62	22710	23333	23960	24591	25225	25863	26504	27149	27798	28451
1.63	29107	29766	30430	31097	31767	32442	33120	33801	34486	35175
1.64	35867	36563	37263	37966	38673	39383	40097	40815	41536	42260
1.65	9.9542989	43721	44456	45195	45938	46684	47434	48187	48944	49704
1.66	50468	51236	52007	52782	53560	54342	55127	55916	56708	57504
1.67	58303	59106	59913	60723	61536	62353	63174	63998	64825	65656
1.68	66491	67329	68170	69015	69864	70716	71571	72430	73293	74159
1.69	75028	75901	76777	77657	78540	79427	80317	81211	82108	83008
1.70	9.9583912	84820	85731	86645	87563	88484	89409	90337	91268	92203
1.71	93141	94083	95028	95977	96929	97884	98843	99805	00771	01740
1.72	602712	03688	04667	05650	06636	07625	08618	09614	10613	11616
1.73	12622	13632	14645	15661	16681	17704	18730	19760	20793	21830
1.74	22869	23912	24959	26009	27062	28118	29178	30241	31308	32377
1.75	9.9633451	34527	35607	36690	37776	38866	39959	41055	42155	43258
1.76	44364	45473	46586	47702	48821	49944	51070	52199	53331	54467
1.77	55606	56749	57894	59043	60195	61350	62509	63671	64836	66004
1.78	67176	68351	69529	70710	71895	73082	74274	75468	76665	77866
1.79	79070	80277	81488	82701	83918	85138	86361	87588	88818	90051
1.80	9.9691287	92526	93768	95014	96263	97515	98770	00029	01291	02555
1.81	703823	05095	06369	07646	08927	10211	11498	12788	14082	15378
1.82	16678	17981	19287	20596	21908	23224	24542	25864	27189	28517
1.83	29848	31182	32520	33860	35204	36551	37900	39254	40610	41969
1.84	43331	44697	46065	47437	48812	50190	51571	52955	54342	55733
1.85	9.9757126	58522	59922	61325	62730	64139	65551	66966	68384	69805
1.86	71230	72657	74087	75521	76957	78397	79839	81285	82734	84186
1.87	85640	87098	88559	90023	91490	92960	94433	95909	97389	98871
1.88	800356	01844	03335	04830	06327	07827	09331	10837	12346	13859
1.89	15374	16893	18414	19939	21466	22996	24530	26066	27606	29148
1.90	9.9830693	32242	33793	35348	36905	38465	40028	41595	43164	44736
1.91	46311	47890	49471	51055	52642	54232	55825	57421	59020	60621
1.92	62226	63834	65445	67058	68675	70294	71917	73542	75170	76802
1.93	78436	80073	81713	83356	85002	86651	88302	89957	91614	93275
1.94	94938	96605	98274	99946	01621	03299	04980	06663	08350	10039
1.95	9.9911732	13427	15125	16826	18530	20237	21947	23659	25375	27093
1.96	28815	30539	32266	33995	35728	37464	39202	40943	42688	44435
1.97	46185	47937	49693	51451	53213	54977	56744	58513	60286	62062
1.98	63840	65621	67405	69192	70982	72774	74570	76368	78169	79972
1.99	81779	83588	85401	87216	89034	90854	92678	94504	96333	98165

TABLE 34

ZONAL SPHERICAL HARMONICS *

Degrees	P_1	P_2	P_3	P_4	P_5	P_6	P_7
0	+ 1.0000	+ 1.0000	+ 1.0000	+ 1.0000	+ 1.0000	+ 1.0000	+ 1.0000
1	.9998	.9995	.9991	.9985	.9977	.9968	.9957
2	.9994	.9982	.9963	.9939	.9909	.9872	.9830
3	.9986	.9959	.9918	.9863	.9795	.9714	.9620
4	.9976	.9927	.9854	.9758	.9638	.9495	.9329
5	+ 0.9962	+ 0.9886	+ 0.9773	+ 0.9623	+ 0.9437	+ 0.9216	+ 0.8962
6	.9945	.9836	.9674	.9459	.9194	.8881	.8522
7	.9925	.9777	.9557	.9267	.8911	.8492	.8016
8	.9903	.9709	.9423	.9048	.8589	.8054	.7449
9	.9877	.9633	.9273	.8803	.8232	.7570	.6830
10	+ 0.9848	+ 0.9548	+ 0.9106	+ 0.8532	+ 0.7840	+ 0.7045	+ 0.6164
11	.9816	.9454	.8923	.8238	.7417	.6483	.5462
12	.9781	.9352	.8724	.7920	.6966	.5891	.4731
13	.9744	.9241	.8511	.7582	.6489	.5273	.3980
14	.9703	.9122	.8283	.7224	.5990	.4635	.3218
15	+ 0.9659	+ 0.8995	+ 0.8042	+ 0.6847	+ 0.5471	+ 0.3983	+ 0.2455
16	.9613	.8860	.7787	.6454	.4937	.3323	+ .1700
17	.9563	.8718	.7519	.6046	.4391	.2661	+ .0961
18	.9511	.8568	.7240	.5624	.3836	.2002	+ .0248
19	.9455	.8410	.6950	.5192	.3276	.1353	− .0433
20	+ 0.9397	+ 0.8245	+ 0.6649	+ 0.4750	+ 0.2715	+ 0.0719	− 0.1072
21	.9336	.8074	.6338	.4300	.2156	+ .0106	.1664
22	.9272	.7895	.6019	.3845	.1602	− .0481	.2202
23	.9205	.7710	.5692	.3386	.1057	− .1038	.2680
24	.9135	.7518	.5357	.2926	.0525	− .1558	.3094
25	+ 0.9063	+ 0.7321	+ 0.5016	+ 0.2465	+ 0.0009	− 0.2040	− 0.3441
26	.8988	.7117	.4670	.2007	− .0489	.2478	.3717
27	.8910	.6908	.4319	.1553	− .0964	.2869	.3922
28	.8829	.6694	.3964	.1105	− .1415	.3212	.4053
29	.8746	.6474	.3607	.0665	− .1839	.3502	.4113
30	+ 0.8660	+ 0.6250	+ 0.3248	+ 0.0234	− 0.2233	− 0.3740	− 0.4102
31	.8572	.6021	.2887	− .0185	.2595	.3924	.4022
32	.8480	.5788	.2527	− .0591	.2923	.4053	.3877
33	.8387	.5551	.2167	− .0982	.3216	.4127	.3671
34	.8290	.5310	.1809	− .1357	.3473	.4147	.3409
35	+ 0.8192	+ 0.5065	+ 0.1454	− 0.1714	− 0.3691	− 0.4114	− 0.3096
36	.8090	.4818	.1102	.2052	.3871	.4031	.2738
37	.7986	.4567	.0755	.2370	.4011	.3898	.2343
38	.7880	.4314	.0413	.2666	.4112	.3719	.1918
39	.7771	.4059	.0077	.2940	.4174	.3497	.1470
40	+ 0.7660	+ 0.3802	− 0.0252	− 0.3190	− 0.4197	− 0.3236	− 0.1006
41	.7547	.3544	.0574	.3416	.4181	.2939	− .0535
42	.7431	.3284	.0887	.3616	.4128	.2610	− .0064
43	.7314	.3023	.1191	.3791	.4038	.2255	+ .0398
44	.7193	.2762	.1485	.3940	.3914	.1878	+ .0846
45	+ 0.7071	+ 0.2500	− 0.1768	− 0.4063	− 0.3757	− 0.1484	+ 0.1271
46	.6947	.2238	.2040	.4158	.3568	− .1078	.1667
47	.6820	.1977	.2300	.4227	.3350	− .0665	.2028
48	.6691	.1716	.2547	.4270	.3105	− .0251	.2350
49	.6561	.1456	.2781	.4286	.2836	+ .0161	.2626
50	+ 0.6428	+ 0.1198	− 0.3002	− 0.4275	− 0.2545	+ 0.0564	+ 0.2854

* Calculated by Mr. C. E. Van Orstrand for this publication.

TABLE 34 (*continued*)

ZONAL SPHERICAL HARMONICS

Degrees	P_1	P_2	P_3	P_4	P_5	P_6	P_7
50	+ 0.6428	+ 0.1198	− 0.3002	− 0.4275	− 0.2545	+ 0.0564	+ 0.2854
51	.6293	.0941	.3209	.4239	.2235	.0954	.3031
52	.6157	.0686	.3401	.4178	.1910	.1326	.3154
53	.6018	.0433	.3578	.4093	.1571	.1677	.3221
54	.5878	.0182	.3740	.3984	.1223	.2002	.3234
55	+ 0.5736	− 0.0065	− 0.3886	− 0.3852	− 0.0868	+ 0.2297	+ 0.3191
56	.5592	.0310	.4016	.3698	− .0509	.2560	.3095
57	.5446	.0551	.4131	.3524	− .0150	.2787	.2947
58	.5299	.0788	.4229	.3331	+ .0206	.2976	.2752
59	.5150	.1021	.4310	.3119	+ .0557	.3125	.2512
60	+ 0.5000	− 0.1250	− 0.4375	− 0.2891	+ 0.0898	+ 0.3232	+ 0.2231
61	.4848	.1474	.4423	.2647	.1229	.3298	.1916
62	.4695	.1694	.4455	.2390	.1545	.3321	.1572
63	.4540	.1908	.4471	.2121	.1844	.3302	.1203
64	.4384	.2117	.4470	.1841	.2123	.3240	.0818
65	+ 0.4226	− 0.2321	− 0.4452	− 0.1552	+ 0.2381	+ 0.3138	+ 0.0422
66	.4067	.2518	.4419	.1256	.2615	.2997	+ .0022
67	.3907	.2710	.4370	.0955	.2824	.2819	− .0375
68	.3746	.2895	.4305	.0651	.3005	.2606	− .0763
69	.3584	.3074	.4225	.0344	.3158	.2362	− .1135
70	+ 0.3420	− 0.3245	− 0.4130	− 0.0038	+ 0.3281	+ 0.2089	− 0.1485
71	.3256	.3410	.4021	+ .0267	.3373	.1791	.1808
72	.3090	.3568	.3898	.0568	.3434	.1472	.2099
73	.2924	.3718	.3761	.0864	.3463	.1136	.2352
74	.2756	.3860	.3611	.1153	.3461	.0788	.2563
75	+ 0.2588	− 0.3995	− 0.3449	+ 0.1434	+ 0.3427	+ 0.0431	− 0.2730
76	.2419	.4122	.3275	.1705	.3362	+ .0070	.2850
77	.2250	.4241	.3090	.1964	.3267	− .0290	.2921
78	.2079	.4352	.2894	.2211	.3143	− .0644	.2942
79	.1908	.4454	.2688	.2443	.2990	− .0990	.2913
80	+ 0.1736	− 0.4548	− 0.2474	+ 0.2659	+ 0.2810	− 0.1321	− 0.2835
81	.1564	.4633	.2251	.2859	.2606	.1635	.2708
82	.1392	.4709	.2020	.3040	.2378	.1927	.2536
83	.1219	.4777	.1783	.3203	.2129	.2193	.2321
84	.1045	.4836	.1539	.3345	.1861	.2431	.2067
85	+ 0.0872	− 0.4886	− 0.1291	+ 0.3468	+ 0.1577	− 0.2638	− 0.1778
86	.0698	.4927	.1038	.3569	.1278	.2810	.1460
87	.0523	.4959	.0781	.3648	.0969	.2947	.1117
88	.0349	.4982	.0522	.3704	.0651	.3045	.0755
89	.0175	.4995	.0262	.3739	.0327	.3105	.0381
90	+ 0.0000	− 0.5000	− 0.0000	+ 0.3750	+ 0.0000	− 0.3125	− 0.0000

Table 35

CYLINDRICAL HARMONICS OF THE 0TH AND 1ST ORDERS

$$J_n(x) = \frac{x^n}{2^n\Gamma(n+1)}\left\{1 - \frac{x^2}{2^2(n+1)} + \frac{x^4}{2^4\,2!\,(n+1)(n+2)} \cdots\right\}. \qquad J_1(x) = -J_0'(x) = \frac{dJ_0(x)}{dx}.$$

x	$J_0(x)$	$J_1(x)$	x	$J_0(x)$	$J_1(x)$	x	$J_0(x)$	$J_1(x)$	x	$J_0(x)$	$J_1(x)$
.00	unity	zero	**.50**	.938470	.242268	**1.00**	.765198	.440051	**1.50**	.511828	.557937
.01	.999975	.005000	.51	.936024	.246799	.01	.760781	.443286	.51	.506241	.559315
.02	.999900	.010000	.52	.933534	.251310	.02	.756332	.446488	.52	.500642	.560653
.03	.999775	.014998	.53	.930998	.255803	.03	.751851	.449658	.53	.495028	.561951
.04	.999600	.019996	.54	.928418	.260277	.04	.747339	.452794	.54	.489403	.563208
.05	.999375	.024992	**.55**	.925793	.264732	**1.05**	.742796	.455897	**1.55**	.483764	.564424
.06	.999100	.029987	.56	.923123	.269166	.06	.738221	.458966	.56	.478114	.565600
.07	.998775	.034979	.57	.920410	.273581	.07	.733616	.462001	.57	.472453	.566735
.08	.998401	.039968	.58	.917652	.277975	.08	.728981	.465003	.58	.466780	.567830
.09	.997976	.044954	.59	.914850	.282349	.09	.724316	.467970	.59	.461096	.568883
.10	.997502	.049938	**.60**	.912005	.286701	**1.10**	.719622	.470902	**1.60**	.455402	.569896
.11	.996977	.054917	.61	.909116	.291032	.11	.714898	.473800	.61	.449698	.570868
.12	.996403	.059892	.62	.905184	.295341	.12	.710146	.476663	.62	.443985	.571798
.13	.995779	.064863	.63	.903209	.299628	.13	.705365	.479491	.63	.438262	.572688
.14	.995106	.069829	.64	.900192	.303893	.14	.700556	.482284	.64	.432531	.573537
.15	.994383	.074789	**.65**	.897132	.308135	**1.15**	.695720	.485041	**1.65**	.426792	.574344
.16	.993610	.079744	.66	.894029	.312355	.16	.690856	.487763	.66	.421045	.575111
.17	.992788	.084693	.67	.890885	.316551	.17	.685965	.490449	.67	.415290	.575836
.18	.991916	.089636	.68	.887698	.320723	.18	.681047	.493098	.68	.409528	.576520
.19	.990995	.094572	.69	.884470	.324871	.19	.676103	.495712	.69	.403760	.577163
.20	.990025	.099501	**.70**	.881201	.328996	**1.20**	.671133	.498289	**1.70**	.397985	.577765
.21	.989005	.104422	.71	.877890	.333096	.21	.666137	.500830	.71	.392204	.578326
.22	.987937	.109336	.72	.874539	.337170	.22	.661116	.503334	.72	.386418	.578845
.23	.986819	.114241	.73	.871147	.341220	.23	.656071	.505801	.73	.380628	.579323
.24	.985652	.119138	.74	.867715	.345245	.24	.651000	.508231	.74	.374832	.579760
.25	.984436	.124026	**.75**	.864242	.349244	**1.25**	.645906	.510623	**1.75**	.369033	.580156
.26	.983171	.128905	.76	.860730	.353216	.26	.640788	.512979	.76	.363229	.580511
.27	.981858	.133774	.77	.857178	.357163	.27	.635647	.515296	.77	.357422	.580824
.28	.980496	.138632	.78	.853587	.361083	.28	.630482	.517577	.78	.351613	.581096
.29	.979085	.143481	.79	.849956	.364976	.29	.625295	.519819	.79	.345801	.581327
.30	.977626	.148319	**.80**	.846287	.368842	**1.30**	.620086	.522023	**1.80**	.339986	.581517
.31	.976119	.153146	.81	.842580	.372681	.31	.614855	.524189	.81	.334170	.581666
.32	.974563	.157961	.82	.838834	.376492	.32	.609602	.526317	.82	.328353	.581773
.33	.972960	.162764	.83	.835050	.380275	.33	.604329	.528407	.83	.322535	.581840
.34	.971308	.167555	.84	.831228	.384029	.34	.599034	.530458	.84	.316717	.581865
.35	.969609	.172334	**.85**	.827369	.387755	**1.35**	.593720	.532470	**1.85**	.310898	.581849
.36	.967861	.177100	.86	.823473	.391453	.36	.588385	.534444	.86	.305080	.581793
.37	.966067	.181852	.87	.819541	.395121	.37	.583031	.536379	.87	.299262	.581695
.38	.964224	.186591	.88	.815571	.398760	.38	.577658	.538274	.88	.293446	.581557
.39	.962335	.191316	.89	.811565	.402370	.39	.572266	.540131	.89	.286631	.581377
.40	.960398	.196027	**.90**	.807524	.405950	**1.40**	.566855	.541948	**1.90**	.281819	.581157
.41	.958414	.200723	.91	.803447	.409499	.41	.561427	.543726	.91	.276008	.580896
.42	.956384	.205403	.92	.799334	.413018	.42	.555981	.545464	.92	.270201	.580595
.43	.954306	.210069	.93	.795186	.416507	.43	.550518	.547162	.93	.264397	.580252
.44	.952183	.214719	.94	.791004	.419965	.44	.545038	.548821	.94	.258596	.579870
.45	.950012	.219353	**.95**	.786787	.423392	**1.45**	.539541	.550441	**1.95**	.252799	.579446
.46	.947796	.223970	.96	.782536	.426787	.46	.534029	.552020	.96	.247007	.578983
.47	.945533	.228571	.97	.778251	.430151	.47	.528501	.553559	.97	.241220	.578478
.48	.943224	.233154	.98	.773933	.433483	.48	.522958	.555050	.98	.235438	.577934
.49	.940870	.237720	.99	.769582	.436783	.49	.517400	.556518	.99	.229661	.577349
.50	.938470	.242268	**1.00**	.765198	.440051	**1.50**	.511828	.557937	**2.00**	.223891	.576725

CYLINDRICAL HARMONICS OF THE 0TH AND 1ST ORDERS

$J_1(x) = -J_0'(x)$. Other orders may be obtained from the relation, $J_{n+1}(x) = \frac{2n}{x} J_n(x) - J_{n-1}(x)$.

$J_{-n}(x) = (-1)^n J_n(x)$.

x	$J_0(x)$	$J_1(x)$	x	$J_0(x)$	$J_1(x)$	x	$J_0(x)$	$J_1(x)$	x	$J_0(x)$	$J_1(x)$
2.00	.223891	.576725	**2.50**	−.048384	.497094	**3.00**	−.260052	.339059	**3.50**	−.380128	.137378
.01	.218127	.576060	.51	−.053342	.494606	.01	−.263424	.335319	.51	−.381481	.133183
.02	.212370	.575355	.52	−.058276	.492086	.02	−.266758	.331563	.52	−.382791	.128989
.03	.206620	.574611	.53	−.063184	.489535	.03	−.270055	.327789	.53	−.384060	.124795
.04	.200878	.573827	.54	−.068066	.486953	.04	−.273314	.323998	.54	−.385287	.120601
2.05	.195143	.573003	**2.55**	−.072923	.484340	**3.05**	−.276535	.320191	**3.55**	−.386472	.116408
.06	.189418	.572139	.56	−.077753	.481696	.06	−.279718	.316368	.56	−.387615	.112216
.07	.183701	.571236	.57	−.082557	.479021	.07	−.282862	.312529	.57	−.388717	.108025
.08	.177993	.570294	.58	−.087333	.476317	.08	−.285968	.308675	.58	−.389776	.103836
.09	.172295	.569313	.59	−.092083	.473582	.09	−.289036	.304805	.59	−.390793	.099650
2.10	.166607	.568292	**2.60**	−.096805	.470818	**3.10**	−.292064	.300921	**3.60**	−.391769	.095466
.11	.160929	.567233	.61	−.101499	.468025	.11	−.295054	.297023	.61	−.392703	.091284
.12	.155262	.566134	.62	−.106165	.465202	.12	−.298005	.293110	.62	−.393595	.087106
.13	.149607	.564997	.63	−.110803	.462350	.13	−.300916	.289184	.63	−.394445	.082931
.14	.143963	.563821	.64	−.115412	.459470	.14	−.303788	.285244	.64	−.395253	.078760
2.15	.138330	.562607	**2.65**	−.119992	.456561	**3.15**	−.306621	.281291	**3.65**	−.396020	.074593
.16	.132711	.561354	.66	−.124543	.453625	.16	−.309414	.277326	.66	−.396745	.070431
.17	.127104	.560063	.67	−.129065	.450660	.17	−.312168	.273348	.67	−.397429	.066274
.18	.121509	.558735	.68	−.133557	.447668	.18	−.314881	.269358	.68	−.398071	.062122
.19	.115929	.557368	.69	−.138018	.444648	.19	−.317555	.265356	.69	−.398671	.057975
2.20	.110362	.555963	**2.70**	−.142449	.441601	**3.20**	−.320188	.261343	**3.70**	−.399230	.053834
.21	.104810	.554521	.71	−.146850	.438528	.21	−.322781	.257319	.71	−.399748	.049699
.22	.099272	.553041	.72	−.151220	.435428	.22	−.325335	.253284	.72	−.400224	.045571
.23	.093749	.551524	.73	−.155559	.432302	.23	−.327847	.249239	.73	−.400659	.041450
.24	.088242	.549970	.74	−.159866	.429150	.24	−.330319	.245184	.74	−.401053	.037336
2.25	.082750	.548378	**2.75**	−.164141	.425972	**3.25**	−.332751	.241120	**3.75**	−.401406	.033229
.26	.077274	.546750	.76	−.168385	.422769	.26	−.335142	.237046	.76	−.401718	.029131
.27	.071815	.545085	.77	−.172597	.419541	.27	−.337492	.232963	.77	−.401989	.025040
.28	.066373	.543384	.78	−.176776	.416288	.28	−.339801	.228871	.78	−.402219	.020958
.29	.060947	.541646	.79	−.180922	.413011	.29	−.342069	.224771	.79	−.402408	.016885
2.30	.055540	.539873	**2.80**	−.185036	.409709	**3.30**	−.344296	.220663	**3.80**	−.402556	.012821
.31	.050150	.538063	.81	−.189117	.406384	.31	−.346482	.216548	.81	−.402664	.008766
.32	.044779	.536217	.82	−.193164	.403035	.32	−.348627	.212425	.82	−.402732	.004722
.33	.039426	.534336	.83	−.197177	.399662	.33	−.350731	.208296	.83	−.402759	.000687
.34	.034092	.532419	.84	−.201157	.396267	.34	−.352793	.204160	.84	−.402746	−.003337
2.35	.028778	.530467	**2.85**	−.205102	.392849	**3.35**	−.354814	.200018	**3.85**	−.402692	−.007350
.36	.023483	.528480	.86	−.209014	.389408	.36	−.356793	.195870	.86	−.402599	−.011352
.37	.018208	.526458	.87	−.212890	.385945	.37	−.358731	.191716	.87	−.402465	−.015343
.38	.012954	.524402	.88	−.216733	.382461	.38	−.360628	.187557	.88	−.402292	−.019322
.39	.007720	.522311	.89	−.220540	.378955	.39	−.362482	.183394	.89	−.402079	−.023289
2.40	.002508	.520185	**2.90**	−.224312	.375427	**3.40**	−.364296	.179226	**3.90**	−.401826	−.027244
.41	−.002683	.518026	.91	−.228048	.371879	.41	−.366067	.175054	.91	−.401534	−.031186
.42	−.007853	.515833	.92	−.231749	.368311	.42	−.367797	.170878	.92	−.401202	−.035115
.43	−.013000	.513606	.93	−.235414	.364722	.43	−.369485	.166699	.93	−.400832	−.039031
.44	−.018125	.511346	.94	−.239043	.361113	.44	−.371131	.162516	.94	−.400422	−.042933
2.45	−.023227	.509052	**2.95**	−.242636	.357485	**3.45**	−.372735	.158331	**3.95**	−.399973	−.046821
.46	−.028306	.506726	.96	−.246193	.353837	.46	−.374297	.154144	.96	−.399485	−.050695
.47	−.033361	.504366	.97	−.249713	.350170	.47	−.375818	.149954	.97	−.398959	−.054555
.48	−.038393	.501974	.98	−.253196	.346484	.48	−.377296	.145763	.98	−.398394	−.058400
.49	−.043401	.499550	.99	−.256643	.342781	.49	−.378733	.141571	.99	−.397791	−.062229
2.50	−.048384	.497094	**3.00**	−.260052	.339059	**3.50**	−.380128	.137378	**4.00**	−.397150	.066043

CYLINDRICAL HARMONICS OF THE 0TH AND 1ST ORDERS

TABLE 36.—4-place Values for $x = 4$ to 15

x	$J_0(x)$	$J_1(x)$	x	$J_0(x)$	$J_1(x)$
4.0	−.3972	−.0660	9.5	−.1939	+.1613
.1	−.3887	−.1033	.6	−.2090	.1395
.2	−.3766	−.1386	.7	−.2218	.1166
.3	−.3610	−.1719	.8	−.2323	.0928
.4	−.3423	−.2028	.9	−.2403	.0684
4.5	−.3205	−.2311	10.0	−.2459	.0435
.6	−.2961	−.2566	.1	−.2490	+.0184
.7	−.2693	−.2791	.2	−.2496	−.0066
.8	−.2404	−.2985	.3	−.2477	−.0313
.9	−.2097	−.3147	.4	−.2434	−.0555
5.0	−.1776	−.3276	10.5	−.2366	−.0789
.1	−.1443	−.3371	.6	−.2276	−.1012
.2	−.1103	−.3432	.7	−.2164	−.1224
.3	−.0758	−.3460	.8	−.2032	−.1422
.4	−.0412	−.3453	.9	−.1881	−.1603
5.5	−.0068	−.3414	11.0	−.1712	−.1768
.6	+.0270	−.3343	.1	−.1528	−.1913
.7	.0599	−.3241	.2	−.1330	−.2039
.8	.0917	−.3110	.3	−.1121	−.2143
.9	.1220	−.2951	.4	−.0902	−.2225
6.0	.1506	−.2767	11.5	−.0677	−.2284
.1	.1773	−.2559	.6	−.0446	−.2320
.2	.2017	−.2329	.7	−.0213	−.2333
.3	.2238	−.2081	.8	+.0020	−.2323
.4	.2433	−.1816	.9	.0250	−.2290
6.5	.2601	−.1538	12.0	.0477	−.2234
.6	.2740	−.1250	.1	.0697	−.2157
.7	.2851	−.0953	.2	.0908	−.2060
.8	.2931	−.0652	.3	.1108	−.1943
.9	.2981	−.0349	.4	.1296	−.1807
7.0	.3001	−.0047	12.5	.1469	−.1655
.1	.2991	+.0252	.6	.1626	−.1487
.2	.2951	.0543	.7	.1766	−.1307
.3	.2882	.0826	.8	.1887	−.1114
.4	.2786	.1096	.9	.1988	−.0912
7.5	.2663	.1352	13.0	.2069	−.0703
.6	.2516	.1592	.1	.2129	−.0489
.7	.2346	.1813	.2	.2167	−.0271
.8	.2154	.2014	.3	.2183	−.0052
.9	.1944	.2192	.4	.2177	+.0166
8.0	.1717	.2346	13.5	.2150	.0380
.1	.1475	.2476	.6	.2101	.0590
.2	.1222	.2580	.7	.2032	.0791
.3	.0960	.2657	.8	.1943	.0984
.4	.0692	.2708	.9	.1836	.1165
8.5	.0419	.2731	14.0	.1711	.1334
.6	.0146	.2728	.1	.1570	.1488
.7	−.0125	.2697	.2	.1414	.1626
.8	−.0392	.2641	.3	.1245	.1747
.9	−.0653	.2559	.4	.1065	.1850
9.0	−.0903	.2453	14.5	.0875	.1934
.1	−.1142	.2324	.6	.0679	.1999
.2	−.1367	.2174	.7	.0476	.2043
.3	−.1577	.2004	.8	.0271	.2066
.4	−.1768	.1816	.9	.0064	.2069
9.5	−.1939	.1613	15.0	−.0142	.2051

TABLE 37.

(*a*) 1st 10 roots (R_m) of $J_0(x) = 0$; $J_1(R_m)$

Higher roots may be calculated to better than 1 part in 10,000 by the approximate formula $R_m = R_{m-1} + \pi$

$R_1 = 2.404826 \quad J_1(R_1) = +0.5191$
$R_2 = 5.520078 \quad J_1(R_2) = -0.3403$
$R_3 = 8.653728 \quad J_1(R_3) = +0.2715$
$R_4 = 11.791534 \quad J_1(R_4) = -0.2325$
$R_5 = 14.930918 \quad J_1(R_5) = +0.2065$
$R_6 = 18.071064 \quad J_1(R_6) = -0.1877$
$R_7 = 21.211637 \quad J_1(R_7) = +0.1733$
$R_8 = 24.352472 \quad J_1(R_8) = -0.1617$
$R_9 = 27.493479 \quad J_1(R_9) = +0.1522$
$R_{10} = 30.634606 \quad J_1(R_{10}) = -0.1442$

(*b*) 1st 15 roots of $J_1(x) = \dfrac{dJ_0(x)}{dx} = 0$ with corresponding values of maximum or minimum values of $J_0(x)$.

No. of root (n)	Root $= x_n$	$J_0(x_n)$
1	3.831706	−.402759
2	7.015587	+.300116
3	10.173468	−.249705
4	13.323692	+.218359
5	16.470630	−.196465
6	19.615859	+.180063
7	22.760084	−.167185
8	25.903672	+.156725
9	29.046829	−.148011
10	32.189680	+.140606
11	35.332308	−.134211
12	38.474766	+.128617
13	41.617094	−.123668
14	44.759319	+.119250
15	47.901461	−.115274

Higher roots may be obtained as under (*a*).

NOTES. $y = J_n(x)$ is a particular solution of Bessel's equation,

$$x^2\frac{d^2y}{dx^2} + x\frac{dy}{dx} + (x^2 - n^2)y = 0.$$

The general formula for $J_n(x)$ is

$$J_n(x) = \sum_0^\infty \frac{(-1)^s x^{n+2s}}{2^{n+2s}\pi s\, \pi(n+s)},$$

or

$$= \sum_0^\infty \frac{(-1)^s x^{n+2s}}{2^{n+2s} s!\,(n+s)!}$$

when n is an integer and

$$J_{n+1}(x) = \frac{2n}{x}J_n(x) - J_{n-1}(x),$$

and

$$J_1(x) = \frac{dJ_0(x)}{dx},$$

$$J_{-n}(x) = (-1)^n J_n(x).$$

Tables 36 to 37 are based upon Gray and Matthews' reprints from Dr. Meissel's tables. See also Reports of British Association, 1907–1916.

ELLIPTIC INTEGRALS

Values of $\int_0^{\frac{\pi}{2}}(1-\sin^2\theta\sin^2\phi)^{\pm\frac{1}{2}}\,d\phi$

This table gives the values of the integrals between 0 and $\pi/2$ of the function $(1-\sin^2\theta\sin^2\phi)^{\pm\frac{1}{2}}\,d\phi$ for different values of the modulus corresponding to each degree of θ between 0 and 90.

θ	$\int_0^{\frac{\pi}{2}}\frac{d\phi}{(1-\sin^2\theta\sin^2\phi)^{\frac{1}{2}}}$		$\int_0^{\frac{\pi}{2}}(1-\sin^2\theta\sin^2\phi)^{\frac{1}{2}}d\phi$		θ	$\int_0^{\frac{\pi}{2}}\frac{d\phi}{(1-\sin^2\theta\sin^2\phi)^{\frac{1}{2}}}$		$\int_0^{\frac{\pi}{2}}(1-\sin^2\theta\sin^2\phi)^{\frac{1}{2}}d\phi$	
	Number.	Log.	Number.	Log.		Number.	Log.	Number.	Log.
0°	1.5708	0.196120	1.5708	0.196120	45°	1.8541	0.268127	1.3506	0.130541
1	5709	196153	5707	196087	6	8691	271644	3418	127690
2	5713	196252	5703	195988	7	8848	275267	3329	124788
3	5719	196418	5697	195822	8	9011	279001	3238	121836
4	5727	196649	5689	195591	9	9180	282848	3147	118836
5°	1.5738	0.196947	1.5678	0.195293	50°	1.9356	0.286811	1.3055	0.115790
6	5751	197312	5665	194930	1	9539	290895	2963	112698
7	5767	197743	5649	194500	2	9729	295101	2870	109563
8	5785	198241	5632	194004	3	9927	299435	2776	106386
9	5805	198806	5611	193442	4	2.0133	303901	2681	103169
10°	1.5828	0.199438	1.5589	0.192815	55°	2.0347	0.308504	1.2587	0.099915
1	5854	200137	5564	192121	6	0571	313247	2492	096626
2	5882	200904	5537	191362	7	0804	318138	2397	093303
3	5913	201740	5507	190537	8	1047	323182	2301	089950
4	5946	202643	5476	189646	9	1300	328384	2206	086569
15°	1.5981	0.203615	1.5442	0.188690	60°	2.1565	0.333753	1.2111	0.083164
6	6020	204657	5405	187668	1	1842	339295	2015	079738
7	6061	205768	5367	186581	2	2132	345020	1920	076293
8	6105	206948	5326	185428	3	2435	350936	1826	072834
9	6151	208200	5283	184210	4	2754	357053	1732	069364
20°	1.6200	0.209522	1.5238	0.182928	65°	2.3088	0.363384	1.1638	0.065889
1	6252	210916	5191	181580	6	3439	369940	1545	062412
2	6307	212382	5141	180168	7	3809	376736	1453	058937
3	6365	213921	5090	178691	8	4198	383787	1362	055472
4	6426	215533	5037	177150	9	4610	391112	1272	052020
25°	1.6490	0.217219	1.4981	0.175545	70°	2.5046	0.398730	1.1184	0.048589
6	6557	218981	4924	173876	1	5507	406665	1096	045183
7	6627	220818	4864	172144	2	5998	414943	1011	041812
8	6701	222732	4803	170348	3	6521	423596	0927	038481
9	6777	224723	4740	168489	4	7081	432660	0844	035200
30°	1.6858	0.226793	1.4675	0.166567	75°	2.7681	0.442176	1.0764	0.031976
1	6941	228943	4608	164583	6	8327	452196	0686	028819
2	7028	231173	4539	162537	7	9026	462782	0611	025740
3	7119	233485	4469	160429	8	9786	474008	0538	022749
4	7214	235880	4397	158261	9	3.0617	485967	0468	019858
35°	1.7312	0.238359	1.4323	0.156031	80°	3.1534	0.498777	1.0401	0.017081
6	7415	240923	4248	153742	1	2553	512591	0338	014432
7	7522	243575	4171	151393	2	3699	527613	0278	011927
8	7633	246315	4092	148985	3	5004	544120	0223	009584
9	7748	249146	4013	146519	4	6519	562514	0172	007422
40°	1.7868	0.252068	1.3931	0.143995	85°	3.8317	0.583396	1.0127	0.005465
1	7992	255085	3849	141414	6	4.0528	607751	0086	003740
2	8122	258197	3765	138778	7	3387	637355	0053	002278
3	8256	261406	3680	136086	8	7427	676027	0026	001121
4	8396	264716	3594	133340	9	5.4349	735192	0008	000326
45°	1.8541	0.268127	1.3506	0.130541	90°	∞	∞	1.0000	——

TABLE 39

MOMENTS OF INERTIA, RADII OF GYRATION, AND WEIGHTS

In each case the axis is supposed to traverse the centre of gravity of the body. The axis is one of symmetry. The mass of a unit of volume is w.

Body.	Axis.	Weight.	Moment of Inertia I_0.	Square of Radius of Gyration ρ_0^2.
Sphere of radius r	Diameter	$\frac{4\pi w r^3}{3}$	$\frac{8\pi w r^5}{15}$	$\frac{2r^2}{5}$
Spheroid of revolution, polar axis $2a$, equatorial diameter $2r$	Polar axis	$\frac{4\pi w a r^2}{3}$	$\frac{8\pi w a r^4}{15}$	$\frac{2r^2}{5}$
Ellipsoid, axes $2a$, $2b$, $2c$	Axis $2a$	$\frac{4\pi w abc}{3}$	$\frac{4\pi w abc(b^2+c^2)}{15}$	$\frac{b^2+c^2}{5}$
Spherical shell, external radius r, internal r'	Diameter	$\frac{4\pi w(r^3-r'^3)}{3}$	$\frac{8\pi w(r^5-r'^5)}{15}$	$\frac{2(r^5-r'^5)}{5(r^3-r'^3)}$
Ditto, insensibly thin, radius r, thickness dr	Diameter	$4\pi w r^2 dr$	$\frac{8\pi w r^4 dr}{3}$	$\frac{2r^2}{3}$
Circular cylinder, length $2a$, radius r	Longitudinal axis $2a$	$2\pi w a r^2$	$\pi w a r^4$	$\frac{r^2}{2}$
Elliptic cylinder, length $2a$, transverse axes $2b$, $2c$	Longitudinal axis $2a$	$2\pi w abc$	$\frac{\pi w abc(b^2+c^2)}{2}$	$\frac{b^2+c^2}{4}$
Hollow circular cylinder, length $2a$, external radius r, internal r'	Longitudinal axis $2a$	$2\pi w a(r^2-r'^2)$	$\pi w a(r^4-r'^4)$	$\frac{r^2+r'^2}{2}$
Ditto, insensibly thin, thickness dr	Longitudinal axis $2a$	$4\pi w a r dr$	$4\pi w a r^3 dr$	r^2
Circular cylinder, length $2a$, radius r	Transverse diameter	$2\pi w a r^2$	$\frac{\pi w a r^2(3r^2+4a^2)}{6}$	$\frac{r^2}{4}+\frac{a^2}{3}$
Elliptic cylinder, length $2a$, transverse axes $2a$, $2b$	Transverse axis $2b$	$2\pi w abc$	$\frac{\pi w abc(3c^2+4a^2)}{6}$	$\frac{c^2}{4}+\frac{a^2}{3}$
Hollow circular cylinder, length $2a$, external radius r, internal r'	Transverse diameter	$2\pi w a(r^2-r'^2)$	$\frac{\pi w a}{6}\left\{\begin{array}{l}3(r^4-r'^4)\\+4a^2(r^2-r'^2)\end{array}\right\}$	$\frac{r^2+r'^2}{4}+\frac{a^2}{3}$
Ditto, insensibly thin, thickness dr	Transverse diameter	$4\pi w a r dr$	$\pi w a(2r^3+\frac{4}{3}a^2 r)dr$	$\frac{r^2}{2}+\frac{a^2}{3}$
Rectangular prism, dimensions $2a$, $2b$, $2c$	Axis $2a$	$8wabc$	$\frac{8wabc(b^2+c^2)}{3}$	$\frac{b^2+c^2}{3}$
Rhombic prism, length $2a$, diagonals $2b$, $2c$	Axis $2a$	$4wabc$	$\frac{2wabc(b^2+c^2)}{3}$	$\frac{b^2+c^2}{6}$
Ditto	Diagonal $2b$	$4wabc$	$\frac{2wabc(c^2+2a^2)}{3}$	$\frac{c^2}{6}+\frac{a^2}{3}$

(Taken from Rankine.)

For further mathematical data see Smithsonian Mathematical Tables, Becker and Van Orstrand (Hyperbolic, Circular and Exponential Functions); Smithsonian Mathematical Formulae and Tables of Elliptic Functions, Adams and Hippisley; Functionentafeln, Jahnke und Emde (xtgx, x^{-1}tgx, Roots of Transcendental Equations, $a+bi$ and $re^{\theta i}$, Exponentials, Hyperbolic Functions, $\int_0^x \frac{\sin u}{u}du$, $\int_x^\infty \frac{\cos u}{u}du$, $\int_\infty^{-x}\frac{e^{-u}}{u}du$, Fresnel Integral, Gamma Function, Gauss Integral $\frac{2}{\sqrt{\pi}}\int_0^x e^{-x^2}dx$, Pearson Function $e^{-\frac{1}{2}\pi\nu}\int_0^\pi \sin^r e^{\nu x}dx$, Elliptic Integrals and Functions, Spherical and Cylindrical Functions, etc.). For further references see under Tables, Mathematical, in the 11th ed. Encyclopædia Britannica. See also Carr's Synopsis of Pure Mathematics and Mellor's Higher Mathematics for Students of Chemistry and Physics.

PROBABLE VALUES OF THE GENERAL PHYSICAL CONSTANTS

(As of January 1, 1929)

(Considerably abbreviated from paper by Raymond T. Birge published in Phys. Rev. Suppl., vol. 1, no. 1, July, 1929, which see for further details)

Some of the most important results of physical science are embodied in the numerical magnitudes of various universal constants; the accurate determination of such constants has engaged the time and labor of many most eminent scientists. Some of these constants can be evaluated by various methods. Each has been investigated by various persons, at various times, and each investigation normally produces a result more or less different from that of any other investigation. Under such conditions there arises a general and continuous need for a searching examination of the *most probable* value of each important constant. An investigation of the values of general constants in current use reveals a surprising inconsistency, both in regard to the actually adopted values and to their origin, probably because of the fact that it is almost impossible to find a critical study of the best values, sufficiently up-to-date to be really reliable, and sufficiently detailed to explain the inconsistencies found among older tables.

(1) In what follows " each general constant has been determined from the available data, beginning with that constant whose value depends least on other constants. The value thus adopted has then been used *consistently* in the calculation of each succeeding constant for which it is an ' auxiliary constant '. No attempt has been made to compare the results of different investigators until these have been made properly comparable by the use of the same value of each auxiliary constant.

(2) " Each constant has been calculated from the available data by the use, as far as possible, of formulas which involve no approximations.

(3) " Each constant has been recalculated, whenever it seemed necessary, by analytic methods—usually by the method of least squares."

Attention should be directed to two important sources:

(1) The International Critical Tables (1926) publish a list of nine so-called "Accepted Basic Constants," each with its " Uncertainty." A list is given of 21 constants derived from these, and also certain other conventional and experimental constants. The I.C.T.[1] list was adopted in 1923; since then important work on nearly every constant has appeared. It was prepared with the aid of various scientific societies and individuals. The values are not claimed to be the best values then available, although obviously an attempt was made to obtain the best values. The chief weakness of this list is the lack of any statement as to their origins. By correspondence and in other ways Doctor Birge has obtained such information, and specific references to this are made in the various sections to follow.

[1] I.C.T. will be used for International Critical Tables, 1926.

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(2) The Geiger and Scheel "Handbuch der Physik"[1] contains an article by F. Henning and W. Jaeger on "The General Physical Constants." There is a list of 52 constants, basic and derived, and a statement as to the theoretical and numerical basis of each value. Many approximations and sources of inconsistency are pointed out, but with one or two exceptions no attempt is made to recalculate data to improve the published values. The Henning and Jaeger article, written in 1926, contains more recent information than the I.C.T.

Since 1926 much new material has appeared, so that practically every constant adopted in the present paper differs more or less in value from that given in either of these two preceding lists. In fact for the great majority of the constants considered the adopted value is based primarily on work which has appeared since 1926. In the case of most of the constants, the situation is now much more satisfactory than it was a few years ago.

The velocity of light in vacuum (c).—An accurate summary of all numerical results to 1927, in which many errors in the literature are corrected, has been given by de Bray.[2] A good recent account of the experimental methods for measuring c, as well as the numerical results, is that by Ladenburg.[3]

The latest and most accurate direct determination of the velocity of light is that by Michelson,[4] in 1921-1926. When the various sets of results are collected under the five different mirrors used, the agreement is quite remarkable, all five results varying only from 299797 to 299795 with a mean of 299796 as before.

$$\mathbf{c} = (2.99796 \pm 0.00004) \times 10^{10}\ \text{cm} \cdot \text{sec.}^{-1}$$

The velocity of electromagnetic waves may be obtained *indirectly* from the measured ratio of the electrostatic (*es*) to the electromagnetic (*em*) system of electrical units, according to the generally accepted electromagnetic theory of light. The best value of this ratio, which is here denoted by c', is undoubtedly that found by Rosa and Dorsey.[5] Their final result is the average of a very large number of individual results, taken at different times, under varying conditions, and of remarkable consistency. It seems to Doctor Birge that about one part in 30000 is a very conservative estimate for the *probable* error, giving $c' = 2.9971 \pm 0.0001$.

This result is in terms of international electrical units. Henning and Jaeger[6] show that, to obtain the true ratio between the *es* and the *em* system, in absolute units, the result of Rosa and Dorsey must be multiplied by $p^{1/2}$, where one int. ohm $= p$ abs. ohm. According to a subsequent discussion, $p = 1.00051 \pm 0.00002$. This gives a corrected value of $c' = (2.9979 \pm 0.0001) \times 10^{10}$ cm · sec^{-1}. It is in beautiful agreement with Michelson's recent value of c.

[1] Henceforth denoted by H.P. [2] Nature, 120, 602, 1927. [3] Handb. der Exp. Phys., 18, 1, 1928. [4] Astrophys. Journ. 65, 1, 1927. [5] Bur. Standards Bull., 3, 433, 1907. [6] H.P., 2, 507.

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The Newtonian constant of gravitation (G).—The H.P.[1] gives a table of seven determinations of G, ranging from 6.60 to 6.70×10^{-8} dyne · cm² · g⁻². Henning and Jaeger adopt 6.65. In their list they omit Poynting's value[2] of 6.66 ± 0.01. The I.C.T. adopt as one of their basic constants $G = 6.66 \pm 0.01$.

Since the publication of these reviews, Heyl[3] has made undoubtedly the most reliable determination of G. His final result is

$$\mathbf{G = (6.664 \pm 0.002) \times 10^{-8}\ dyne \cdot cm^2 \cdot g^{-2}}$$

This result is adopted here. It is based on five separate determinations varying from 6.661 to 6.667.

Mean density of the earth.—Assuming $R = 6.371 \times 10^8$ cm as the mean radius of the earth, as given in the H.P., and $g_{45} = 980.616$ cm · sec⁻², $G \cdot \delta(\text{earth}) = 36.797 \times 10^{-8}$ sec⁻², where δ(earth) is the *mean density* of the earth. From the H.P. result $G = 6.65$ $\delta(\text{earth}) = 5.53$ g · cm⁻³. With the new result $G = 6.664$

$$\delta(\text{earth}) = \mathbf{5.522 \pm 0.002\ g \cdot cm^{-3}}$$

Relation of the liter to the cubic decimeter (1000 cm³).—The liter is defined as the volume of a kilogram of air-free water at its maximum density. In other words, the maximum density of water is, by definition, one kg · l⁻¹. The kilogram is defined as the mass of the prototype kilogram preserved in Paris. This original prototype was intended to be the mass of a cubic decimeter (dm³) of water, at maximum density. Later determinations have shown a slight discrepancy. The various experimental results are discussed by Henning and Jaeger.[4] The mean of the best determinations is 1 liter = 1000.027 cm³; this value has been accepted in all recent tables. Henning and Jaeger give no probable error for the result, but one unit in the last place seems a reasonable assumption. Hence

$$\mathbf{1\ liter = 1000.027 \pm 0.001\ cm^3 = 1.000027 \pm 0.000001\ dm^3}$$

The maximum density of water $\delta_m(H_2O)$ is accordingly

$$\mathbf{1/1.000027 = 0.999973 \pm 0.000001\ kg \cdot dm^{-3}\ or\ g \cdot cm^{-3}}$$

It should be noted in conclusion, that it is customary to define 1 cc as liter/1000, while 1 cm³ = liter/1000.027.

The normal mole volume of an ideal gas.—

$$(\nu_n\ \text{cm}^3 \cdot \text{mole}^{-1},\ \text{or}\ R_n\ \text{liter} \cdot \text{mole}^{-1})$$

The normal mole volume of an ideal gas is the volume occupied by one gram mole of an ideal gas, at 0° C, under one normal atmosphere pressure. This

[1] H.P., 2, 507. [2] "Gravitation," Encyc. Brit., XI ed. [3] Proc. Nat. Acad. Sci., 13, 601, 1927. Heyl's more recent value is 6.670×10^{-8} cm³ · g⁻¹ · sec.⁻² Bur. Standards Journ. Res., 5, 1243, 1930. [4] H.P., 2, 491.

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quantity can theoretically be determined from any real gas, correcting to reduce to an ideal gas. Actually, only oxygen is used because its atomic weight is 16.000 by definition; there is no error in the resulting value due to error in the atomic weight. As a result of extensive investigations, the correction to change oxygen to an ideal gas is known with considerable accuracy.

The I.C.T. gives $\nu_n = 22.4115 \times 10^3$ cm³. The H.P. gives $22.414_5 \times 10^3$ cm³ or $R_n = 22.413_9$ liters. The discrepancy must be due to different values of $\delta_n(O_2)$, the normal density of oxygen, or of $(1-\alpha)$, the factor due to the deviation of oxygen from an ideal gas.[1] Thus

$$\nu_n = 32(1-\alpha)/\delta_n(O_2) = \{32(1-\alpha)/L_n(O_2)\}1000.027 = R_n(1000.027)$$

where ν_n is the normal mole volume in cm³, R_n the same in liters, $\delta_n(O_2)$ the normal density of O_2, in grams per cm³, and $L_n(O_2)$ the normal density in grams per liter. All these values correspond to normal gravity ($g_n = 980.665$). It is, however, customary among chemists to express the experimental results in terms of g_{45} (980.616). Such values will be denoted by ν, δ, L, and R. Thus

$$R = M(1-\alpha)/L$$

where M is the molecular weight.

[1] The most general definition of α is $(1/pv)\ d(pv)/d(p)$, (temp. = constant); it measures the change in pv, per unit change in pressure, and has the dimensions of pressure^{-1}. To make the numerical values more definite, it is customary to write $\alpha = [1/(pv)_1]\ d(pv)/d(p)$, where $(pv)_1$ refers to unit pressure. In investigations on normal density or normal mole volume, it is natural to choose one atmosphere as the unit of pressure. Henning and Heuse use one meter of mercury as the unit of p, and denote α by κt (see page 85). Since the numerical magnitude of α is proportional to the size of the unit of p, we have $\kappa t = 100\alpha/76$. Henning (H.P. 9, 528) uses the symbol κt, but states that p is measured in atmospheres.

Within limits of error, the isothermal pv is a linear function of p, for the so-called permanent gases O_2, N_2, H_2, etc., for such substances α is independent of p but is a function of temperature, and is more properly written αt. The linear extrapolation of pv to $p = 0$ gives then $(pv)_0 = (1-\alpha)(pv)_1$. Now in the limit $p = 0$, any gas becomes, by definition, an ideal gas. Hence $(pv)_0$ is the constant pv of an ideal gas, and $(1-\alpha)$ is the factor which converts the real $(pv)_1$, (unit pressure) into the ideal $(pv)_0$, both at some definite temperature. $(1-\alpha)$ is often denoted by $(1+\lambda)$, and $(1-\alpha)$ or $(1+\lambda)$ may be defined as the ratio $(pv)_0/(pv)_1$. Frequently v is so chosen (in magnitude or unit) that $(pv)_1$ is unity. α (or κt) is then numerically (but *not* dimensionally) the *slope* of the pv isothermal (see H.P. 9, 528 and 538).

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Henning and Jaeger[1] give as a mean value, $L = 1.42892$ g · l^{-1} and $(1-a) = 1.00092$. A more recent result by Baxter and Starkweather[2] ($L = 1.42901$) is omitted, but is included in the discussion by Henning and Jaeger, and raises the mean L to 1.42893. From this, and the value of $(1-a)$ just quoted, the H.P. gets its value of v_n. The more recent values of $(1-a)$, average 1.00086, and this, taken with the Baxter and Starkweather value of L, gives $v_n = 22.4119 \times 10^3$ cm^3, in close agreement with the I.C.T. value.

Baxter and Starkweather[3] have recalculated their 1926 data in a more logical manner and obtain $L = 1.428965$ grams per liter, $(1-a) = 1.000927$.

$$L = (1.428965 \pm 0.000030) \text{ gram} \cdot \text{liter}^{-1} \ (g = 980.616)$$
$$1 - a = 1.000927 \pm 0.000030.$$

$$\boldsymbol{R} = \mathbf{22.4146 \pm 0.0008 \text{ liter} \cdot \text{mole}^{-1}} \ (\boldsymbol{g}_{45} = \mathbf{980.616})$$
$$\boldsymbol{R}_n = \mathbf{22.4135 \pm 0.0008 \text{ liter} \cdot \text{mole}^{-1}} \ (\boldsymbol{g}_n = \mathbf{980.665})$$
$$v_n = \mathbf{(22.4141 \pm 0.0008) \times 10^3 \text{ cm}^3 \cdot \text{mole}^{-1}} \ (\boldsymbol{g}_n = \mathbf{980.665}).$$

Ratio of international (int.) to absolute (abs.) electrical units.—For practical convenience, the ohm, ampere, and volt have been defined, by international agreement,[4] in terms of definite physical apparatus.[5]

These international units are to be compared with the corresponding absolute units, with which they were of course identical, within limits of experimental error, at the time of adoption in 1908. One abs. ohm $= 10^9$ *em* units of resistance, the *em* unit, under the assumption that permeability is dimensionless, being one cm · sec.$^{-1}$. Measurements of the abs. ohm have been made in a variety of ways, but all methods necessarily involve the measurement of length and time. The abs. ampere is 10^{-1} *em* units, the *em* unit being one dyne$^{1/2}$, again with the assumption of dimensionless permeability.

The definition of the int. amp. just given is the primary definition, and Doctor Birge follows the I.C.T. in designating the int. amp. so defined, and all quantities involving it, by the symbol "(a)." Now let

(1) 1 int. ohm $= p$ abs. ohm (2) 1 int. amp. (a) $= q$ abs. amp.

then

(3) 1 int. coul. (a) $= q$ abs. coul.
(4) 1 int. volt (a) $= pq$ abs. volt
(5) 1 int. joule (a) $= pq^2$ abs. joule
(6) 1 int. henry $= p$ abs. henry
(7) 1 int. gauss $= q$ abs. gauss

[1] H.P., 2, 493. [2] Proc. Nat. Acad. Sci., 10, 476, 1924. [3] Proc. Nat. Acad. Sci., 14, 57, 1928. [4] London, 1908. [5] This book, p. xlvi et seq.

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The int. ohm can be constructed as a definite laboratory standard. This is not true of the int. amp. (a). Hence the 1908 London conference appointed a committee to determine the e.m.f. of the Weston normal cell, in terms of the int. ohm and int. amp. The final value adopted by the committee (Jan. 1, 1911) was 1.0183 int. volts, at 20°C, which, to avoid ambiguity, is written 1.01830. This is effectively a new definition of the int. volt and to distinguish it, if necessary, from the primary definition, Doctor Birge again follows the I.C.T. in writing int. volt (v). Similarly all units involving the Weston normal cell will be designated by "(v)." Let

$$1 \text{ int. volt (v)} = r \text{ abs. volt} \tag{8}$$

as contrasted with eq. (4). It is now possible to use the int. volt (v) and the int. ohm to obtain a new (subsidiary) definition of the int. amp. Thus

$$1 \text{ int. amp. (v)} = r/p \text{ abs. amp.} \tag{9}$$

as compared to eq. (2). Finally, in many investigations, a so-called "semi-absolute" volt has been used. This is defined as the e.m.f. required to force one *abs.* amp. of current through one *int.* ohm resistance. Hence from eq. (1)

$$1 \text{ semiabs. volt} = p \text{ abs. volt.} \tag{10}$$

From eqs. (8) and (10) one obtains

$$1 \text{ int. volt (v)} = r/p \text{ semiabs. volt.} \tag{11}$$

We have now to consider the most probable value of p and of q, and the difference, if any, between r and pq (or between r/p and q). These questions are discussed by Henning and Jaeger in the H.P., and they conclude,

$$q = 1, \qquad p = 1.0005_0, \qquad r = pq = 1.0005_0.$$

On the other hand, the I.C.T. gives

$$q = 0.99993, \quad p = 1.00052, \quad r = 1.00042, \quad \text{while} \quad pq = 1.00045.$$

Hence $r/p = 0.99990 \neq q$. The correct determination of the best values of p and q is a very technical and extremely involved matter. Unfortunately, as just seen, there is no exact agreement on the subject. Part of the present disagreement in the values of p and q is due to the fact that there is no standard international unit of resistance or of voltage. Each national laboratory has its own standards which differ more or less among themselves, and also may change with time. The values of p and q finally adopted here represent, as well as possible, *mean* values both in respect to place and to time. Fortunately the accuracy of these quantities is so great that any possible error in the finally adopted values is entirely immaterial in its effect on the many constants derived later in this paper.

The numerical relation of the int. and abs. ohm rests chiefly on two extensive investigations, one $p=1.00052 \pm 0.00004$, by Smith,[1] at the National Physical Laboratory (N.P.L.) of England, and the other, $p=1.00051$, by Grüneisen and Giebe,[2] at the German Reichsanstalt. The latter estimate their probable error, as well as that of Smith, as about 3 parts in 10^5. In 1925 a committee at the N.P.L. began an investigation of the relation of the int. and abs. electrical units. This work is incomplete. It was stated in 1925[3] that a comparison of various manganin with mercury resistances indicates that the former have all increased in resistance by about 2.5 parts per 10^5 since 1912, or that the mercury standards (defining the int. ohm) are really smaller by this amount. The latter assumption would give $p=1.000495$, in place of Smith's value of 1.00052. In a recent investigation at the Reichsanstalt, Steinwehr and Schulze[4] evidently assume that the N.P.L. 1925 standards are 2 parts in 10^5 less than the older 1912 standards, giving a mean value of p in exact agreement with the 1920 Reichsanstalt value. Their own experiments in 1928 agree with this same mean value to ± 1 in 10^5. Various intercomparisons at the N.P.L.[5] show that the German and American standards lie between the 1912 and 1925 N.P.L. values. It seems certain that the best value of p, at the present time, is 1.00051 (p.e. seems to be not more than 2 parts in 10^5).

The most probable value of q is more uncertain. In the older work, the abs. amp., determined with either a current balance or a tangent galvanometer, was compared directly with the int. amp. as measured by a silver voltameter. There was measured by means of a silver voltameter, with certain specifications, the amount of silver, in grams, deposited per sec. by a current of one abs. amp. This mass of silver was then compared with 0.00111800 gram, the defined amount deposited, *under the same conditions*, by one int. amp. per sec.

Such a procedure determines q unambiguously, but does not necessarily evaluate the electrochemical equivalent of silver (E_{Ag}) per abs. coul. The electrochemical equivalent of a substance is the mass actually associated with unit charge, and is independent of experimental imperfections, while the mass deposited in an electrolytic cell per unit charge—the only quantity we can actually measure—*is* subject to experimental imperfections. This distinction has no bearing on the value of q, so long as one accepts the official definition of the int. ampere. It concerns only the value of electrochemical equivalents and the resulting value of the faraday. The various experimental values of q, determined as explained above, are listed by Henning and Jaeger.[6]

[1] Philos. Trans., 214, 27, 1914. [2] Ann. Phys., 63, 179, 1920. [3] N.P.L. Reports, p. 94, 1925. [4] Ann. Phys., 87, 769, 1928. [5] N.P.L. Reports, p. 8, 1927. [6] H.P., 2, 499.

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In the later work (1906 to date) the current, measured in abs. amp., usually with a current balance, is sent through an int. ohm resistance, using a Weston normal cell. From the known current in abs. amp. and the known resistance in int. ohms, one obtains the e.m.f. of the Weston cell in semiabsolute volts. By eq. (11) the ratio of this result to the e.m.f. in int. volt (v), (1.01830 by definition), is r/p, evaluating only r/p, and not q.

The value of the e.m.f. of the Weston cell, in semiabs. volts, the assumed corresponding electrochemical equivalent of silver per abs. coul., and the true resulting value of r/p, are listed by Henning and Jaeger.[1] Omitting a probably less accurate value by Guthe, the remaining four values range from 1.00006 to 0.99989. Henning and Jaeger give correctly as 1.01822 semiabs. volts the Rosa, Dorsey and Miller[2] value of the e.m.f. of the Weston cell, but misquote and use in their averages the resulting E_{Ag} and r/p, giving 0.99995 for r/p in place of the true 0.99992 ($=1.01822/1.01830$). Using 0.99992, the unweighted average of the four investigations[3] is $r/p=0.99995$. The Bureau of Standards[4] considers only (a) (c) and (d) of reference 3 and gives 0.99991 as the best average value of r/p. The I.C.T. value (0.99990) is based on (a) and (d) only. Henning and Jaeger[1] take the unweighted average of all four values, and Doctor Birge has done the same, since there seem to be differences of opinion as to the relative weighting of these four values. It is very probable that (c) should be given a relatively lower weight; the final average is fortunately not changed.

The next question concerns the equality of r/p and q. Rosa, Vinal and McDaniel[5] determined the e.m.f. of the Weston cell as 1.01827 int. volt (a), by using a silver voltameter and an int. ohm resistance. Hence by eqs. (4) and (8), knowing 1.01827 int. volt (a) = 1.01830 int. volt (v), $pq/r=1.01830/1.01827=1.00003$. Hence $q=1.00003\ r/p$. These investigators naturally assumed $r/p=0.99992$, for reference 3 (d). Hence $q=0.99995$. This is the figure misquoted as r/p, by Henning and Jaeger.[1]

The result indicates that q differs from r/p by 3 parts in 10^5, and that, to agree with the primary int. units, the Weston cell should have been taken as 1.01827 int. volts. But at the Reichsanstalt,[6] the corresponding quantity was found, in 1908, to be 1.01834 int. volts, and in 1922, 1.01831. The average of these three results indicates that the accepted value of 1.01830 int. volts is correct within limits of error. In other words, $q=r/p$, and one int. volt (a) = one int. volt (v). This agrees with the view of Henning and Jaeger.[7] The relative values of q and r/p adopted by the I.C.T. are based directly on the work of the Bureau of Standards.[2, 6]

[1] H.P., 2, 500, Table 6. [2] Bur. Standards Bull., 8, 269, 1912. [3] (a) Ayrton, Mather, Smith, (N.P.L.) 1908, $r/p=0.99989$, (b) Janet, Laporte, Jouaust, 1908, 1.00006, (c) Haga, Boerema, 1913, 0.99994, (d) Rosa, Dorsey, Miller (Bur. Standards), 1912, 0.99992. [4] Bur. Standards Circ. 60, 38, 1916. [5] Bur. Standards Bull., 10, 475, 1914. [6] Z. Instrument., 28, 327 and 353, 1908; ibid., 42, 221, 1922. [7] H.P., 2, 501.

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Henning and Jaeger [1] consider that the variation from unity of either r/p or q is less than the experimental error, and think it more practical to assume $r/p=q=1.0000$. It seems best to accept the mean value of $r/p=0.99995$, determined in four different laboratories, with the probable error as ± 0.00005. Assuming then no distinction between int. volt (v), and int. volt (a), we have

$$p=1.00051\pm 0.00002 \qquad pq=1.00046\pm 0.00005$$
$$q=0.99995\pm 0.00005 \qquad pq^2=1.00041\pm 0.00010$$

The atomic weights of certain elements.—In evaluating some of our constants, it is necessary to use the atomic weights of various elements. In the ultimate analysis, only ratios of atomic weights enter our formulas for the general constants. All atomic weights are determined from ratios, but in general not directly from the particular ratios we need. Hence it is necessary to consider individual atomic weights.

The present atomic weights are based on the arbitrary assumption that the weight of oxygen is 16 exactly. In choosing oxygen as a basis, it is assumed that it has always the same atomic weight; i. e., it has no isotopes. Giauque and Johnston [2] have very recently found an isotope of atomic weight 18, from an analysis of the atmospheric absorption bands of oxygen. H. D. Babcock states that experiments performed on absorption coefficients in these bands indicate that O_{18} has an abundance of only one part in 1250 (probable error some 25 per cent). Aston's atomic weights should be greater than the chemical values by about one part in 10,000. Babcock's determination of relative abundance, involves the *assumption* that the absorption coefficient is the same, per molecule, for each species of molecule ($O_{16}-O_{16}$ and $O_{16}-O_{18}$), and this may not be true. The atomic weights determined by Aston,[3] from the mass spectrograph, need not be identical with those determined by chemical means, since Aston's atomic weights are based on the mass 16 isotope of oxygen considered as exactly 16, while the chemical atomic weights are based on the ordinary mixture of the two isotopes considered as exactly 16. We shall see that Aston's atomic weights of hydrogen, helium, nitrogen and iodine seem to agree with the chemical values within his *limit* of error (one part in ten thousand to one part in five thousand).

Hydrogen.—Moles [4] lists nine results lying in the narrow range 1.00766 to 1.00783, with a mean value of 1.00777 ± 0.00002, or a rounded figure of 1.0078. The final average represents the result of 223 different measurements by five different investigators, using four different methods, and seems to be the most reliable now available. Doctor Birge accordingly adopts

[1] H.P., 2, 501. [2] Journ. Amer. Chem. Soc., 51, 1436, 1929. [3] Proc. Roy. Soc., 115 A, 487, 1927. [4] Berichte, 61 B, 1, 1928; 59, SII, (A) 1926.

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$$H = 1.00777 \pm 0.00002.$$

Aston, from positive ray analysis, obtains H = 1.00778 with a limit of error 0.00015. The recent discovery of an isotope of oxygen makes it permissible to use Aston's value only as an indication of the relative abundance of O_{18} and O_{16}, not as an atomic weight determination. It is in perfect agreement with the chemical value, which indicates a very low abundance of O_{18}.

Helium.—The true atomic weight of helium must be close to Aston's value. The chemical value is at present slightly less accurate than Aston's, and Doctor Birge accordingly adopts his value but his assumed error as the *probable* error, although he considers such a procedure may be open to criticism, in view of the situation regarding the oxygen isotopes. He accordingly writes

$$He = 4.0022 \pm 0.0004.$$

Nitrogen.—The error in the atomic weight of nitrogen produces practically the entire error in the atomic weight of silver. Since the great majority of the accepted atomic weights are derived more directly from silver than from oxygen, that of silver is of the highest importance.

The atomic weight of nitrogen can be obtained by direct comparison with oxygen, and also from density measurements, using the adopted value of R. According to Clarke,[1] the final average of these two methods gives N = 14.0076. The atomic weight can be obtained indirectly in many ways. The results of all methods, including the two just mentioned, are summarized by Clarke[1] and give N = 14.0081, presumably the best value in 1920. Now it is generally agreed that, as in the case of helium, the atomic weight of nitrogen can be determined most accurately from its density and deviation from a perfect gas, by the use of $R = M(1-a)/L$ where R is 22.4146 ± 0.0008 (see p. 77), $(1-a) = 1.00043 \pm 0.00002$,[2] and $L = 1.25046 \pm 0.000045$ [3] whence

$$N = 14.0083 \pm 0.008.$$

Aston[4] obtains N = 14.008, but his assumed accuracy is only one part in 5000. Aston gives always the *limit* of error, and his *probable* error should be much smaller. His values all agree beautifully with the chemical values; the decision as to his actual probable error may be left open.

Silver.—The best atomic weight of silver is at present directly dependent on that of nitrogen. A summary is given by Moles and Clavera.[2] Of the many methods for obtaining the value of Ag, the most accurate is based on the reduc-

[1] Mem. Nat. Acad. Sci., 16, 1920. [2] Z. anorg. Chem., 167, 49, 1927. [3] Ibid., 167, 40, 1927. [4] Proc. Roy. Soc., 115 A, 487, 1927.

tion of $AgNO_3$ to Ag. Since $O = 16.000$, by definition, the sole error is due to that in N. The proportional error is due to that in NO_3, only about one fourth the probable proportional error in N. The ratio $AgNO_3/Ag$ can be determined with great precision. The most accurate ratio, by far, is that by Richards and Forbes,[1] yielding also 1.57479. A very elaborate investigation by Hönigschmid, Zintl and Thile,[2] gives again exactly the same ratio. With our adopted value of N and the above value of $AgNO_3/Ag = r$, one has $NO_3/(r-1) = (62.0083 \pm 0.0008)/(0.57479) = 107.8799 \pm 0.0014$.

The atomic weight of silver can be obtained in many ways. Clarke[3] lists 43 methods, yielding a final weighted average of 107.8804. It seems reasonable that at the present time only the $AgNO_3/Ag$ ratio results need be considered, with a final real error in Ag due merely to that in N. It seems reasonable to adopt

$$\mathbf{Ag = 107.880 \pm 0.001.}$$

Iodine.—The atomic weight of iodine enters into the discussion of the value of the faraday. Clarke[3] lists eight methods, with a mean of 126.926. This result will bear closer scrutiny. The most accurate is the direct determination of the I/Ag ratio, assuming the atomic weight of silver as known. Among the values of this ratio, 1.176603, obtained by Baxter,[4] in 1910, is the most reliable. Clarke lists all determinations. Now the four earlier results are all approximately 1.1753, while the later results run much higher. These earlier results probably are vitiated by some systematic error. They are quite self consistent, and so by Clarke are given a high weighting. With the four earlier results eliminated, we have a new weighted average of 1.176549, in closer agreement with Baxter's 1910 result. This ratio, combined with $Ag = 107.880$, gives $I = 126.926$, while Baxter's result gives 126.932. Using the revised average value for the I/Ag ratio with Clarke's results for the other seven methods, we obtain a final weighted average of $I = 126.932$, in place of Clarke's value 126.926, and in exact agreement with Baxter's result. Doctor Birge adopts

$$\mathbf{I = 126.932 \pm 0.002.}$$

In conclusion it is of interest to note that Aston gets $I = 126.932$, in exact agreement with our adopted value.

Carbon.—The atomic weight of carbon can be determined directly from oxygen. The result of all such determinations, as obtained by Clarke,[3] is 12.0000 ± 0.00026. This result (written 12.000) was accepted in 1925 by the International Committee on Atomic Weights,[5] and has since been used by Baxter.[6]

[1] Journ. Amer. Chem. Soc., 29, 808, 1907. [2] Z. anorg. Chem., 163, 65, 1927. [3] Mem. Nat. Acad. Sci., 16, 1920. [4] Journ. Amer. Chem. Soc., 32, 1591, 1910. [5] Journ. Amer. Chem. Soc., 47, 597, 1925. [6] Journ. Amer. Chem. Soc., 50, 603, 1928.

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Thirteen methods, including the above, listed by Clarke, give a weighted mean of 12.0025 ± 0.00019. Aston[1] finds C=12.0036, (limit of error 0.0012). The mean of the final Clarke value and Aston's value is 12.003, and is adopted here.

$$\mathbf{C = 12.003 \pm 0.001.}$$

Calcium.—The atomic weight of calcium is needed for the grating space of calcite. The value of Ca, accepted since 1911, is 40.07. When readopted in 1925 by the International Committee, reference was made to the work of Richards and Hönigschmid.[2] These investigators precipitate $CaCl_2$ by a solution of Ag, and determine the amount of AgCl produced. They assume Ag=107.88 and Cl=35.457. The final result is Ca=40.075, based on four determinations ranging from 40.085 to 40.070. It seems probable that the Richards and Hönigschmid value of 40.075 is the best. The probable error 0.005, is very uncertain.

$$\mathbf{Ca = 40.075 \pm 0.005.}$$

The normal atmosphere (A_n).—The normal atmosphere is defined as the pressure due to a column of Hg 76 cm high, of normal density (0°C, A_n), under normal gravity.

The I.C.T. gives $A_n = 1.013250 \times 10^6$ dyne · cm^{-2}, based on the definition of A_n as the pressure of a column of a liquid of density 13.5951 g per cm^3, normal gravity. The H.P. gives $A_n = 1.01325_3 \times 10^6$, from the defining equation $A_n = H_n \cdot \rho_n(\mathrm{Hg}) \cdot \delta_m(\mathrm{H_2O}) \cdot g_n$, in which H_n=height of normal barometer=76.000 cm, ρ_n=normal specific gravity of Hg (at 0°C, A_n), referred to air-free water of max. density, $\delta_m(\mathrm{H_2O})$=max. density of water, g_n=normal gravity[4]=980.665 cm · sec.$^{-2}$. Henning and Jaeger,[3] using the density of mercury in the definition, investigate the most probable value of ρ_n, then *adopt* $\rho_n = 13.5955$. The value of $\delta_m(\mathrm{H_2O})$ is 0.999973 g · cm^{-3}. The product $\rho_n(\mathrm{Hg}) \cdot \delta_m(\mathrm{H_2O}) = D_n = 13.5955 \times 0.999973 = 13.595133$ g · cm^{-3}, agreeing with the I.C.T. value to the six significant figures given by the I.C.T., but, with the use of seven figures, leading to A_n=1,013,253, as given by the H.P.

Doctor Birge adopts as the most probable value of ρ_n, the figure calculated by Scheel and Blankenstein,[4] viz. 13.59546. $D_n = 13.59546 \times 0.999973 = 13.59509$ g · cm^{-3}, and $A_n = 13.59509 \times 76 \times 980.665 = 1.013249 \times 10^6$ dyne · cm^{-2}. This should have a probable error of not more than two or three units in the last digit, ± 0.000003.

The 45° atmosphere is obtained by the mere substitution of g_{45}(980.616) for g_n.

$$\boldsymbol{A_n} = \mathbf{(1.013249 \pm 0.000003) \times 10^6\ dyne \cdot cm^{-2}.}$$
$$\boldsymbol{A_{45}} = \mathbf{(1.013199 \pm 0.000003) \times 10^6\ dyne \cdot cm^{-2}.}$$

[1] Proc. Roy. Soc., 115 A, 487, 1927. [2] Z. anorg. Chem., 163, 315, 1927. [3] H.P., 2, 490, 494. [4] Z. Phys., 31, 202, 1925.

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Note.—It is evident that the definition of the normal atmosphere given by Dorsey in the I.C.T. is technically quite different from Henning and Jaeger's in the H.P. The I.C.T. definition makes the normal atmosphere a conventional constant, with no probable error. Doctor Birge had some correspondence on this matter with Doctor Dorsey, leading to the conclusion that the H.P. definition is correct. The adopted value is therefore based on this H.P. definition.

Unfortunately, an article by Burgess[1] was overlooked in which the "standard atmosphere" is defined as "the pressure due to a column of mercury 760 mm high, having a mass of 13.5951 $g \cdot cm^{-3}$, gravitational acceleration of 980.665 $cm \cdot sec.^{-1}$, and is equal to 1,013,250 $dyne \cdot cm^{-2}$." It is thus a conventional constant, with no error. This definition was adopted in 1927 by the International Commission of Weights and Measures. Fortunately, this definition makes no change in the magnitude or the error of any derived constant. It should be noted that no temperature is specified and that the word "mercury" is technically superfluous. This seems very objectionable, since there is thus technically no simple method for reducing to standard atmospheres an actual barometer reading at an actual observed temperature. The H.P. definition, as used by Doctor Birge, seems preferable, in spite of international agreement.

The absolute temperature of the ice-point (T_0).—The generally accepted value of T_0 was, for many years, 273.09°K., based on Berthelot's analysis[2] of the data of Chappuis,[3] and of Joule and Thomson for the porous plug experiment. The final average value was $\gamma = 36618 \times 10^{-7}$, or $T_0 = 273.09°$. The I.C.T. gives $T_0 = 273.1$ as one of its basic constants.

Most extensive observations on the volume and pressure coefficients (α and β) of certain gases have recently been made by Henning and Heuse,[4] at the Reichsanstalt. The value of γ was obtained by two different methods.[5]

The first method gave for the gases He, H_2, and N_2, $\gamma \times 10^7 = 36600$, 36607, and 36606, or $T_0 = 273.224°$, 273.172° and 273.179°. The mean is $\gamma \times 10^8 = 366043$ or $T_0 = 273.190° \pm 0.015$.

The second method gave for He (two determinations at slightly different p_0), H_2 and N_2, $\gamma \times 10^7 = 36598$, 36597, 36617, and 36604. The mean is 36604.0 or $T_0 = 273.194°$. They conclude that the best mean value of all the experiments is $\gamma \times 10^7 = 36604$. The reciprocal of this is $T_0 = 273.19°$. They write it as 273.20°. In the later article[4] by Heuse, neon is used, and the above value of γ is confirmed.

The only other determination of T_0 of comparable accuracy is that by Roebuck,[6] using the Joule-Thomson effect in air.[7] This method requires α, the volume coefficient, as well as the Joule-Thomson coefficient μ. Roebuck mea-

[1] Bur. Standards Journ. Res., 1, 635, 1928. [2] Trav. et Mem. Bur. intern., 13, 12, 1907. [3] Ibid., vols. 6, 13. [4] Z. Phys., 5, 264, 1921; 5, 285, 1921; 37, 157, 1926. [5] H.P., 9, 527. [6] Proc. Amer. Acad. Arts and Sci., 60, 537, 1925. [7] H.P., 2, 496.

sured μ, but for a used data, mainly by Chappuis. Henning and Jaeger [1] note this and adopt merely the Henning and Heuse value 273.20° (which as previously noted should be 273.19°). Roebuck obtained three results, 273.18°, 273.16° and 273.12°, average, 273.15°. He lists all previous determinations, and chooses 273.17°, lying midway between his own result and that of Henning and Heuse. He gives ±0.02° as the probable error. Doctor Birge feels that these two results (273.15° and 273.19°) are entitled to far more weight than any of the older work, but that the second result is probably the most accurate, being based on new determinations of a. Hence he adopts—with the probable error given by Henning and Jaeger—

$$T_0 = 273.18 \pm 0.03\,°\mathrm{K}.$$

(Roebuck's ±0.02° may well be more reasonable).

The mechanical equivalent of heat (J) and the electrical equivalent of heat (J').—A description of the methods for the evaluation of J, and a discussion of the results, is given by Jaeger in the H.P.[2] The value adopted by Henning and Jaeger in the H.P.[3] is one $\mathrm{cal.}_{15} = 4.184_2$ int. joule $= 4.186_3$ abs. joule. The I.C.T. value is one $\mathrm{cal.}_{15} = 4.185$ abs. joule. The $\mathrm{cal.}_{15}$ is defined as the amount of thermal energy required to heat one gram of pure water from 14.5° to 15.5°C.

Joule turned mechanical energy directly into thermal energy, and J was evaluated in abs. joules. In most modern work electrical energy is turned directly into thermal, thus evaluating the *electrical* equivalent of heat (J', measured in int. joules). Since the relation between the int. joule and the abs. joule (10^7 ergs) is known with considerable precision, the mechanical equivalent may be obtained from the electrical equivalent.

The value of J adopted by the H.P. results from the work of Jaeger and Steinwehr.[4] They determined J', for many different mean temperatures lying between 4.75°C and 49.60°C. This is undoubtedly the most accurate work now available. They list 67 results. These results are represented as a parabolic function of t.

On examining their data, Doctor Birge finds that a parabola is not a sufficiently complex function. Their residuals show pronounced trends; unfortunately the largest trend is near 15°C. He accordingly made a separate investigation of the best curve for their data.

$$J' = 4.21040 - 2.78958 \times 10^{-3}t + 7.73723 \times 10^{-5}t^2 - 8.52567 \times 10^{-7}t^3 + 3.7540 \times 10^{-9}t^4 \qquad (1)$$

This gives $J'_{15} = 4.18327$ int. joules, and is the most probable value resulting from the work of Jaeger and Steinwehr. Jaeger gives two parts in 10000 (i.e., 8×10^{-4} joules) as the probable error. Doctor Birge therefore writes $J'_{15} = 4.1833 \pm 0.0008$ int. joules. We have one int. joule $= pq^2$ abs. joule, where $pq^2 = 1.00041 \pm 0.00010$. Hence there results

$$J_{15} = (4.1833 \pm 0.0008)(1.00041 \pm 0.00010) = 4.1850 \pm 0.0009 \text{ abs. joules.}$$

[1] H.P., 2, 496. [2] H.P., 9, 476. [3] H.P., 2, 497. [4] Ann. Phys., 64, 305, 1921.

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The most accurate direct determination of the *mechanical* equivalent of heat J is the work of Laby and Hercus,[1] which appeared since the H.P. was compiled. They use a continuous flow calorimeter and make 23 determinations, grouped about six different temperatures, the temperature change in the calorimeter being always about 5°C. Their result is $J=4.1841\pm0.0001$ abs. joules at 16.67°C.

A more precise method of reduction is first to adopt a curve for the temperature variation of the specific heat of water. Such a curve is given immediately by eq. (1). If it is desired that the specific heat at 15°C be unity, eq. (1) is to be divided by 4.18327. Doctor Birge finally adopts

$$\text{one } 15° \text{ calorie } (J_{15}) = 4.1852 \pm 0.0006 \text{ abs. joules}$$
$$\text{one } 15° \text{ '' } (J'_{15}) = 4.1835 \pm 0.0007 \text{ int. joules}$$

and by eq. (1)

$$J_{20} = 4.1813 \pm 0.0006 \text{ abs. joules}$$
$$J'_{20} = 4.1796 \pm 0.0007 \text{ int. joules}$$

The faraday (*F*).—The faraday is defined as the quantity of electricity carried in electrolysis by one gram equivalent of any element. It is believed to be a general constant of nature. According to modern ideas, each univalent ion carries a charge numerically equal to the electronic charge e. The Avogadro number N_0 gives the number of atoms (or molecules) in one gram equivalent. Hence one may define the faraday more precisely as the product $N_0 \cdot e$. The fact that F can be most accurately evaluated from electrolysis, and N_0 is then obtained from F and e, does not affect the validity of the definition.

One electrochemical equivalent is the mass associated with unit electric charge. Like the faraday, its true value, independent of experimental conditions, depends only on the adopted unit of charge. On the other hand we can measure only the amount of a substance deposited or released in an electrolytic cell, per unit current per second. This is affected by experimental conditions, and may or may not equal the electrochemical equivalent. The faraday is then, by definition, the ratio of the gram equivalent of a substance to its electrochemical equivalent. Almost universally the distinction between mass deposited per unit charge, and electrochemical equivalent is ignored. Considerable confusion results regarding the best value of certain electrochemical equivalents, and the resulting best value of the faraday.

Nevertheless, it is convenient to *assume*, for the moment, that the silver deposited per unit charge in a silver voltameter, under the conditions defining the international ampere, is the electrochemical equivalent of silver (E_{Ag}). *With this assumption,* the value of faraday follows from constants already adopted. The gram equivalent of silver, or of any univalent substance, is numerically equal to its atomic weight in grams (Ag). The amount of silver deposited in electrolysis by one international coulomb is, by definition, 0.00111800 gram. Hence

[1] Philos. Trans., A 227, 63, 1927.

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$$F = Ag/0.00111800 = (107.880 \pm 0.001)/0.00111800 \text{ int. coul.}$$
$$= 96494. \pm 1 \text{ int. coul.,} \quad (1)$$
$$= 96489. \pm 5 \text{ abs. coul.} \quad (2)$$

If $q=1$, as adopted by the H.P., $F=96494$ int. coul. *or* abs. coul., the actual value adopted by Henning and Jaeger. If $q=0.99993$, as adopted by the I.C.T., there results $F=96487$ abs. coul. The I.C.T., however, adopts $F=96500 \pm 10$ abs. coul., which with its adopted value of q, leads to $F=96507$ int. coul. This last value requires Ag$=107.893$, in direct contradiction to facts. $F=96500 \pm 10$ abs. coul. is evidently taken from Vinal and Bates,[1] and to understand the seeming discrepancy, it would be necessary to examine in detail this last quoted work employing the distinction between mass carried in electrolysis and mass deposited (see Doctor Birge's discussion, Phys. Rev., Suppl. 1, 35, 1929). Henning and Jaeger[2] make no distinction between mass carried and mass deposited, writing $E_{Ag}=0.00111800$ g per int. coul. It seems evident from Vinal and Bouvard[3] that there *are* inclusions in the silver deposit, tending to make E_{Ag} too large by 4×10^{-8} g, and F too small by 4 coulombs. There may be small parasitic chemical reactions in the silver voltameter, tending to decrease the value of E_{Ag} and hence to increase the value of F. It seemed best to *adopt* the value of F given in eqs. (1) and (2), but to assign to E_{Ag} a probable error of 5×10^{-8} g, i.e., an error slightly greater than the measured effect of the inclusions. Then

$$\boldsymbol{F} = \frac{\mathbf{107.880 \pm 0.001}}{\mathbf{(1.11800 \pm 0.00005) \times 10^{-3}}} = \mathbf{96494 \pm 5 \text{ int. coul.}} \quad (3)$$
$$= \mathbf{96489 \pm 7 \text{ abs. coul.}}$$
$$= \mathbf{9648.9 \pm 0.7 \text{ abs. } \boldsymbol{em} \text{ units,}}$$
$$= \mathbf{(2.89270 \pm 0.00021) \times 10^{14} \text{ abs. } \boldsymbol{es} \text{ units.}}$$

The electronic charge (*e*).—The values of a large number of important constants depend directly on the value of the electronic charge; in most cases the final probable error is due mainly to the error in e. It is desirable that it be determined in many different ways, and by many different persons. The situation has been the reverse. Only one precision method for the evaluation of e was known, and the work had been carried out by a single individual. It is very fortunate that the investigation referred to is a masterpiece. Millikan's[4] investigations extend over more than a decade; the latest value of e was published in 1917. The great importance of e, and because higher values have recently been obtained, led Doctor Birge to investigate the matter in more than usual detail.

Millikan found that if the viscosity of air is taken as constant, in Stokes' law of fall, the apparent value of e is a function of the radius of the drop and of the pressure of the air. The true value of e can be found by assuming a modification of Stokes' law such that his observations could be plotted as a

[1] Bur. Standards Bull., 10, 425, 1914 (p. 447). [2] H.P., 2, 502. [3] Bur. Standards Bull., 13, 147, 1916. [4] Phys. Rev., 29, 60, 1909; 32, 342, 1911; 2, 109, 1913; Philos. Mag., 34, 1, 1917; 19, 209, 1910.

linear graph, its intercept on the y axis giving $e^{2/3}$, and leading to the desired quantity.

Millikan found that for values of $1/pa$ less than about 700 (p in cm Hg, a, radius of drop, in cm), the resulting graph was linear. Only that part of the curve corresponding to $1/pa$ less than 700 was used in precise determinations of e. The 1917 value of e was deduced from 25 oil drops, each giving one point on the graph. The 25 observations form a beautifully consistent set of data. The least squares solution, as calculated by Doctor Birge, gives for the intercept $(61.111 \pm 0.032) \times 10^{-8}$; but plotted data are based on the 1913 value (0.0001824) for the viscosity of air. The value of $a_0 (= e^{2/3})$ is proportional to the viscosity. With the improved 1917 value of the viscosity (0.00018227), $e = a_0^{3/2} = (4.7721 \pm 0.0038) \times 10^{-10}$ *es* units.

Millikan stars 18 of the points, with conditions of observation as perfect as possible. These 18 drops give $a_0 = 61.121 \pm 0.038$ ($e = 4.7733 \pm 0.0045$, 1917 viscosity). These 18 drops deviate from the best straight line more than do the other 7. The standard deviation of the 25 drops is 0.121×10^{-8}, while for the 18 drops it is 0.123×10^{-8}. The drops of smaller radius fall more slowly, and can be more accurately timed. Actually they are less reliable. Thus 13 smaller drops have a standard deviation of 0.134, considered as part of the 25 drops, definitely larger than the 0.121 average of the 25. A least squares solution of these 13 drops gives $a_0 = 61.143 \pm 0.050$, standard deviation of 0.132. This is so close to 0.134 that we can conclude that the 13 drops fit the graph of the entire 25 as well as a graph designed to fit them alone. On the other hand, the 12 larger drops give for the least square solution, $a_0 = 61.078 \pm 0.045$, standard deviation 0.117, thus definitely more reliable than the smaller drops. The resulting value of e, reduced to the 1917 viscosity, is 4.7759 ± 0.0058 for the 13 smaller drops, and 4.7683 ± 0.0053 for the larger drops. The weighted mean is 4.7718, in essential agreement with the value (4.7721) obtained from all 25 drops. This, of course, is what we should expect.

The average deviation from the average for small and large drops is 0.0038, much less than the probable error of either. This is an analytic proof that the true value of e is not a function of the radius of the drop. This also indicates that the larger drops are, if anything, more reliable than the smaller. If the larger are given a higher weight, the resulting value of e would lie between 4.772 and 4.768. The final conclusion is that there is no particular reason for giving different weights to the different drops, and that any such weighting, if made, would slightly lower e. We therefore take 4.772×10^{-10} *es* units as the best result of the 1917 work.

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In 1913 data on 58 drops were obtained. Millikan used, in evaluating e, the 23 drops (out of 58) of smallest $1/pa$. These are more consistent, having a standard deviation of only 0.092. They lead to $e=4.7665\pm0.0058$ (1917 viscosity), while the entire 58 give 4.7703 ± 0.0022. This last figure might appear more reliable than that of 1917; such a conclusion ignores other errors. In 1913 Millikan estimated four factors, each with a maximum uncertainty of 0.1 per cent. In 1917 he estimated two such factors, each with a maximum uncertainty of 0.05 per cent. His final 1917 estimate for the maximum uncertainty in e is 0.1 per cent, based mainly on these two factors. The above calculations show, however, a *probable error* of 0.08 per cent (±0.0038) in the 1917 value, due to accidental errors. The final uncertainty is therefore several times as large. Doctor Birge estimates that the final *probable error* is about 0.1 per cent, and writes $e=(4.772\pm0.005)\times10^{-10}$ *es* units.

This value is now subject to two further corrections. In reducing the result to *es* units per cm, Millikan used $c=2.999\times10^{10}$ cm · sec.$^{-1}$, and made no distinction between international and absolute electrical units. It has been shown definitely that the int. volt differs from the abs. volt by an appreciable amount. We have also now the new value, $c=2.99796$. The change in c is obvious, it lowers e from 4.772 to 4.770. The other change seems to have been overlooked by everyone. Because the electrical potential forces the charged drops against the viscosity of air, instead of against *electrical* resistance, one has *only* electric voltage coming into the calculations. One int. volt$=1.00046\pm0.00005$ abs. volts. The true value of F, in abs. volts, is larger and the true value of e, in abs. *es* units is smaller by just this ratio. Hence, the value of e is reduced[1] from 4.770 to 4.768. Since the error in each of these corrections is negligible, the final result is $e=(4.768\pm0.005)\times10^{-10}$ abs. *es* units. This should be the most reliable value from Millikan's oil-drop work.

Recently an entirely different method has been devised for e. The two results which have already been published are apparently less reliable than the oil-drop value. This new method measures directly the Avogadro number N_0, and from this and the value of the faraday, e immediately follows. It utilizes the absolute wave lengths of X-ray lines, determined with an ordinary ruled grating at grazing incidence, as compared with the wave lengths determined with a crystal grating.

$$\lambda=2d\cdot\sin\theta \tag{1}$$

where d is the grating space. It has been pointed out by Siegbahn,[2] and by

[1] Professor Millikan agreed, 1928. [2] Siegbahn, Spectroscopy of X-rays, p. 26.

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Compton, Beets and DeFoe,[1] that, to obtain the *true* X-ray wave length λ, it is necessary to use an *effective* grating space d, automatically correcting for the refraction of the X rays at the crystal surface. For first order spectra and the high frequencies of ordinary X rays, the *true* grating space d' is connected with the effective space d by the relation

$$d = d'(1 - 0.000135). \qquad (2)$$

Siegbahn uses for calcite $d = 3.02904 \times 10^{-8}$ cm, at 18°C. This is a more or less arbitrary value, assuming that d for rock-salt, at 18°C, is 2.81400×10^{-8} cm. We shall denote by d''_{18} this 3.02904 value, and by λ'' the resulting wave-length. Hence

$$\lambda'' = 2d''_{18} \sin\theta \qquad (2)$$

and

$$\lambda/\lambda'' = d_{18}/d''_{18} \qquad (3)$$

where λ is the true wave length from a ruled grating, d_{18} the effective grating space of calcite at 18° C, λ'' the supposed true wave length from measures with a calcite crystal with d''_{18} as an assumed grating space at 18°C. d_{18} follows knowing d''_{18} and λ. From (2) we obtain d'_{18}, the true grating space of calcite. The temperature coefficient[2] is 1.04×10^{-5}; d'_{20} is accordingly 2.08×10^{-5} larger. This 20° value is given theoretically by the formula

$$d'_{20} = \{nM/\rho N_0 \phi(\beta)\}^{1/3} \qquad (4)$$

where n is $\frac{1}{2}$, M, the molecular weight of calcite ($CaCo_3$), ρ, its density at 20°C, $\phi(\beta)$, a geometrical constant depending on the crystal structure, and N_0, F/e; knowing d'_{20} we can obtain N_0 and then e.

We have $M = 100.078 \pm 0.005$; the best value of ρ is 2.7102 ± 0.0004 g · cm^{-3} (DeFoe, Compton[3]), of $\phi(\beta)$, 1.09630 ± 0.00007 at 20°C (Beets[4]) whence

$$e = (1.7176 \pm 0.0003) \times 10^{13} (d'_{20})^3. \qquad (5)$$

The two published determinations of d_{18}, based on absolute X-ray wave lengths, are by Bäcklin,[5] and Wadlund.[6] Using (3), Wadlund obtains 1.5373 ±0.0008A for the $K\alpha_1$ line of Cu, combined with Siegbahn's values of d''_{18} and λ'', giving $d_{18} = (3.0290 \pm 0.0016) \times 10^{-8}$ cm. The corresponding value of d_{20} is 3.02906; the true grating space d'_{20}, $(3.0295 \pm 0.0016) \times 10^{-8}$ cm. This value is to be substituted in (5). It gives $e = (4.7757 \pm 0.0076) \times 10^{-10}$ abs. *es* units. This is not as accurate as the oil-drop value.

It is difficult to appraise the work of Bäcklin, as regards its accuracy. He gets 8.333±0.008A for the absolute wave length of the Al $K\alpha$ line. Comparing this with an unpublished result by A. Larsson (8.3229±0.0008A), obtained with a crystal, Bäcklin obtains $d_{18} = 3.033 \pm 0.003$A. This gives $d'_{20} = 3.03347$A, and $e = (4.794 \pm 0.015) \times 10^{-10}$ abs. *es* units. This value is 0.55 per cent higher than the oil-drop result.

[1] Phys. Rev., 25, 625, 1925. [2] Siegbahn, Spectroscopy of X-rays, p. 85. [3] Phys. Rev., 25, 618, 1925. [4] Phys. Rev., 25, 621, 1925. [5] Upsala Dissertation, 1928. [6] Proc. Nat. Acad. Sci., 14, 588, 1928; Phys. Rev., 32, 841, 1928.

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Bäcklin's results lead to 4.794 ± 0.015.

The investigation by Bäcklin is a pioneer piece of work, and it is quite likely, as such, to contain unsuspected systematic errors. If the three values of e (4.768 from Millikan's oil-drop work, 4.776 by Wadlund, and 4.794 by Bäcklin) are weighted according to the apparent probable error of each, the result is still suspiciously high. The thorough examination made of the actual value of e and its probable error, from the oil-drop work, was carried out because of this inconsistency. It seems best to reject the Bäcklin value, and to use the weighted mean of the remaining two values, viz. 4.768 ± 0.005 and 4.776 ± 0.008, or 4.770; as usual adopt as its probable error the smaller of the two individual errors, rather than that given by least squares; the latter is meaningless when only two observations are concerned. The finally adopted value is then

$$\boldsymbol{e} = (4.770 \pm 0.005) \times 10^{-10} \text{ abs. } \boldsymbol{es} \text{ units.}$$

The specific charge of the electron (e/m).—A very complete and critical account of all work on the measurement of e/m, up to 1919, has been given by Bestelmeyer.[1] His final conclusion is that $e/m = (1.76 \pm 0.02) \times 10^7$ *em* units. A more recent discussion is that by Gerlach,[2] who concludes that $e/m = 1.766 \times 10^7$ *em* units. The question is discussed very briefly by Henning and Jaeger,[3] who however adopt Gerlach's value. The I.C.T. adopts 1.769 ± 0.003.

The latest work greatly exceeds in accuracy all the preceding; it seems legitimate to confine the discussion to these new results. The value of e/m has been obtained with considerable accuracy by three distinct methods, (a) deflection of electrons in electric and magnetic fields, (*b*) Zeeman effect, (*c*) fine structure and relative wave lengths of H and He^+ spectral lines. It may be obtained also from Bohr's theoretical expression for the Rydberg constant, R_∞, provided one assumes the value of e and of h. This last method is not as accurate as the preceding. A fifth involves the Compton shift. This also is as yet a relatively inaccurate method.

The latest and most accurate work with method (*a*), that by Wolf,[4] is carried out with every possible refinement. The essential point is the employment of a longitudinal magnetic field. The electron velocity is calculated from the potential fall. He concludes that $e/m = (1.7679 \pm 0.0018) \times 10^7$ *em* units. 1.7679 should be corrected for the difference between the int. and abs. units. It then becomes $(1.7689 \pm 0.0018) \times 10^7$ abs. *em* units.

[1] Marx, Handb. Radiologie, 5, 1, 1919. [2] H.P., 22, 41. [3] H.P., 2, 504. [4] Ann. Phys., 83, 849, 1927.

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The most recent accurate work, using method (*b*), is by Babcock.[1] A large number of spectrum lines (116 in all) were employed. Nearly all showed a complex Zeeman pattern. For determining e/m it was necessary to assume the Runge denominator of each line. In cases where this is small, it was known with certainty. In some cases it was large and rather uncertain. His work has been criticized, and Gerlach, in his final table,[2] omits Babcock's result. It appears to Doctor Birge that the criticism is unjustified; at his suggestion, Babcock has recalculated his data, omitting all Zeeman patterns in any way doubtful. The new result,[3] based on 48 lines for which the Zeeman pattern is definitely established, is 1.7606 ± 0.0012; the error is purely observational. The difference between the two values is just that produced by the change in the value of c. Doctor Birge therefore writes $e/m = (1.761 \pm 0.002) \times 10^7$ abs. *em* units as the best result from Zeeman effect.

The latest, most accurate work using method (*c*), is by Houston,[4] based on the Bohr-Sommerfeld model consisting of a positive nucleus and *one* encircling electron (moving in elliptic or circular orbits). Such atoms are H and He^+. In order to determine e/m, we must evaluate the so-called Rydberg constant for hydrogen (R_H) and for ionized helium (R_{He}). Practically the entire error in e/m is merely the error in the *difference* $R_{He} - R_H$.

The pioneer work was performed by Paschen.[5] He obtained $R_H = 109677.69 \pm 0.06$ cm^{-1}, $R_{He} = 109722.14 \pm 0.04$ cm^{-1}. Those give $e/m = 1.768 \pm 0.003$, using his values and assumed errors for R_H and R_{He}, but the present accepted values and errors for H, He, and F. The recent investigation by Houston,[4] is so much more accurate than the work just mentioned that it alone will be considered. Houston's new experimental results are

$$R_{He} = 109722.403 \pm 0.004 \text{ cm}^{-1}, \qquad R_H = 109677.759 \pm 0.008 \text{ cm}^{-1}.$$

The stated errors are purely least squares probable errors. He believes the *relative* values of R_{He} and R_H are correct to 0.02, although the *absolute* error in each may be about 0.05.

Houston used $m = 5.4 \times 10^{-4}$, $He = 4.0001$, $H = 1.0077$, $F = 96470$ abs. coulombs, and obtained $e/m = (1.7606 \pm 0.0010) \times 10^7$ *em* units. Using his constants and the corrected formula the result is 1.7603. The error in his formula is therefore almost negligible. The entire probable error in e/m, due to errors in all factors, aside from $(R_{He} - R_H)$, is less than 0.01 per cent and so is entirely negligible compared to the error in $(R_{He} - R_H)$.

[1] Astrophys. Journ., 58, 149, 1923. [2] H.P., 22, 81. [3] Phys. Rev., 33, 268 A, 1929; Astrophys. Journ., 69, 43, 1929. [4] Phys. Rev., 30, 608, 1927. [5] Ann. Phys., 50, 901, 1916.

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Using Houston's value of R_H, and of $R_{He}-R_H$, together with the values of *H*, *He*, etc., we obtain $e/m=(1.7608\pm0.0008)\times10^7$ abs. *em* units. This value of e/m thus agrees with that obtained by Babcock. Summarizing the results we find $e/m=1.769\pm0.002$ from deflection experiments, $=1.761\pm0.002$ from Zeeman effect, $=1.761\pm0.001$ from H and He spectra. The discrepancy between the first result and the last two is four times the probable error of the first. Theory gives only one chance in 143 of this occurring. The discrepancy seems to be real.

The last two results are measurements of e/m for electrons *inside of an atom*, based upon the quantum theory of atomic structure. The first is the measurement of e/m for electrons *in free space*. The figures point to the conclusion that the e/m of an electron is less when it is *inside* an atom than when it is *outside*. If this conclusion seems unacceptable, then it would appear that there is some general error in the equations of the quantum theory of atomic structure or there is some unknown general error in all the deflection experiments. Under the circumstances two values may be assumed of e/m—one for where atomic structure is involved, the other for free electrons. Hence

$$e/m \text{ (spectroscopic)} = (1.761\pm0.001)\times10^7 \text{ abs. } em \text{ units per g},$$
$$= (5.279\pm0.003)\times10^{17} \text{ abs. } es \text{ " " "},$$
$$e/m \text{ (free electrons)} = (1.769\pm0.002)\times10^7 \text{ abs. } em \text{ " " "},$$
$$= (5.303\pm0.006)\times10^{17} \text{ abs. } es \text{ " " "}.$$

The Planck constant (*h*).—The Planck constant has been evaluated in a number of ways. There is difference of opinion as to the relative accuracy of the results; some are more or less incompatible. A satisfactory determination of this constant is difficult.

The first attempt to obtain a value of *h*, from the results of all seven methods, was made by Doctor Birge in 1919. The value found was $(6.5543\pm0.0025)\times10^{-27}$ erg · sec., the error being merely the least-squares probable error. This error has been criticized by Ladenburg as far too small. It is *not* the final error since, as clearly stated, one must add to it an error somewhat greater than the proportional error in *e*. This occurs with some positive power (unity to two) in every known method for obtaining *h*. This makes the total probable error more nearly ±0.01. Doctor Birge's 1919 evaluation of *h* has been adopted by the I.C.T., but the probable error should be ±0.001.

In 1920 Ladenburg[1] wrote an article on the evaluation of *h*, in which several of Doctor Birge's conclusions were criticized. His own result in that article was 6.54 ± 0.01. In 1925 Ladenburg wrote another article on this subject, for the H.P.[2] He then concludes that $h=6.547$, which value he rounds

[1] Jahrb. Radioakt. und Electronik, 17, 93, 1920. [2] H.P., 23, 279.

off to 6.55±0.01. Henning and Jaeger[1] discuss the most probable value and adopt 6.55.

(a) *Bohr's formula for the Rydberg Constant.*—Bohr's theory of the Hydrogen atom leads to the equation

$$R_\infty = 2\pi^2 e^5 / h^3 c^2 e/m \qquad (1)$$

in which R_∞ is the Rydberg constant for infinite mass (cm^{-1} units), e, the electronic charge (abs. *es* units), and e/m is in *em* units. R_∞ is derived from the observed R_H by the equation

$$R_\infty = R_H(1 + m/m_H) = R_H\{1 + F/(e/m)(H - m) = 109737.424 \text{ cm}^{-1}. \qquad (2)$$

The probable error in R_∞ is about 0.06 cm^{-1}. In absolute units $R_\infty \cdot \text{c} = (3.28988 \pm 0.00004) \times 10^{15}$ sec.^{-1}. Substituting in (1) the spectroscopic value of e/m, since we are dealing with spectroscopic data,

$$h = (6.547 \pm 0.011) \times 10^{-27} \text{ erg} \cdot \text{sec.}$$

After adopting a weighted mean value of h, (1) becomes a method for calculating, indirectly, the value of R_∞. Or, using the directly determined value R_∞, (1) becomes a means for calculating e/m.

(b) *Ionization potentials.*—In 1919 Birge had available 13 values of ionization and resonance potentials. Many more such potentials have been obtained. The probable error in each is rather large. We have one really accurate determination obtained with electrons of carefully controlled velocity. This is Lawrence's value[2] of the ionization potential of Hg. His final value equals 10.40±0.02 int. volts.

The equation for obtaining h is $h\nu = eV$; all quantities are in absolute units. The observed potential (V') is always in int. volts. The potential in abs. *es* units is then $V = pqV'10^8/c$. The spectral frequency ν (in sec.^{-1}) is obtained always from the wave length λ, in cm. Hence $\nu'(\text{cm}^{-1}) = 1/\lambda$, and $\nu = c/\lambda$. The above equations lead to

$$h/e = (pqV'10^8)/(c^2\nu') = (pqV'\lambda 10^8)/c^2 \qquad (3)$$

It seems quite customary to assume that $V_{es} = V'$ volts/300 and to write this equation

$$h/e = V'\lambda/300c. \qquad (4)$$

This is equivalent to assuming $c = 3 \times 10^{10}$ cm · *sec.*$^{-1}$, causing an error of 0.07 per cent. Scarcely anyone uses $c = 3 \times 10^{10}$ cm · sec.^{-1} when reducing λ to ν, and thus in the same equation it is customary to use two different values of c. The "term" of Hg corresponding to the ordinary ionization potential is 84178.5 cm^{-1}, whence

$$h = (6.560 \pm 0.015) \times 10^{-27}.$$

The probable error in V' is 0.2 per cent and in e, 0.1 per cent. The errors of the other factors are negligibly small.

(c) *X-ray continuous spectrum.*—This method uses (3), λ being measured by means of a calcite crystal, i.e., $\lambda = 2d \sin\theta$ where d is the grating space, and θ the angle at which the given wave length shows constructive interference.

$$h/e = pq\,2d(V' \sin\theta)10^8/c^2$$

Duane, Palmer, and Yeh[3] have carried out an accurate investigation. The resulting value of h is $(6.556 \pm 0.009) \times 10^{-27}$. Another result for which equal accuracy is claimed, is by Wagner.[4] Ladenburg[5] gives a complete list of Wagner's experimental results. Ladenburg, using eq. (4), with $c = 2.9985 \times 10^{10}$, gets 6.529±0.01.

[1] H.P., 2, 510. [2] Phys. Rev., 28, 947, 1926. [3] Proc. Nat. Acad. Sci., 7, 237, 1921. [4] Phys. Zeit., 21, 621, 1920. [5] H.P., 23, 296.

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Duane, Palmer, and Yeh used a known potential (int. volts) and measured the angle θ at which the ionization suddenly started (or stopped). This gives the critical ionization frequency corresponding to the given voltage. Wagner used known wave lengths varying the voltage for a given wave length, until ionization suddenly began (or ceased). Both methods involve the calcite grating space d. On page 91 the absolute wave lengths of rays were used to evaluate d', the true grating space; d' was then used with other known constants to evaluate the electronic charge e. In this section we use the finally adopted value of e, $(4.770 \pm 0.005) \times 10^{-10}$ abs. *es* units, with these same constants, to evaluate d'.

$$d'_{20} = \{4.770 \times 10^{-10}/1.7176 \times 10^{13}\}^{\frac{1}{3}} = (3.0283 \pm 0.0010) \times 10^{-8}\text{ cm}$$

This value of d'_{20} *includes* the result of the X-ray work, since the value of e just used is the weighted average from both oil-drop and X-ray work. We might have used $e = 4.768$ to get a value of d' based on oil-drop work. A second value of d' might then be obtained from absolute X-ray measurements. The weighted average of these two values would be the value given, provided we use the data and probable errors indicated on p. 91.

We obtain for the effective grating space of calcite at 20°C, for the first order spectrum,

$$d_{20} = (3.0279 \pm 0.0010) \times 10^{-8}\text{ cm}.$$

This value is to be substituted with the direct experimental value of $V' \sin\theta$. For the latter Duane, Palmer, and Yeh found 2039.9 ± 1 int. volts (mean temperature of about 20°C). Thus we have

$$h = (6.559 \pm 0.008) \times 10^{-27}\text{ erg} \cdot \text{sec}.$$

Similarly revising Wagner's result we obtain 6.532 ± 0.010, in place of 6.526 ± 0.010. It is difficult to judge what revision is required in the values of λ used by Wagner; the change is probably small. We thus have, as the two best values of h, from X-ray data, 6.559 ± 0.008 (or 0.009) and 6.532 ± 0.010. The work of Wagner has not yet been published in sufficient detail. For this reason in adopting a weighted average only one-half as much weight is given to Wagner. Since the two results differ by much more than the probable error of either, the regular least squares probable error is used. Hence, from X-ray data,

$$h = (6.550 \pm 0.009) \times 10^{-27}\text{ erg} \cdot \text{sec}.$$

(d) *Photoelectric effect.*—The most accurate determination of h, from photoelectric work, is by Lukirsky and Prilezaev.[1] They use a somewhat different technique from that employed by Millikan,[2] and obtain a simple empirical relation for the ionization current as a function of voltage. The actual curve may be transposed into a linear graph, making the extrapolation to zero current more certain. They also carry the readings very close to this zero point.

[1] Zeit. Phys., 49, 236, 1928. [2] Phys. Rev., 7, 355, 1916.

The equation for evaluating h is that just used, except that now the energy (P) to pull an electron out of the metal is no longer negligible compared to $h\nu$. Hence we write

$$Ve = h\nu - P.$$

To eliminate P, light of varying frequencies is used, measuring for each the critical voltage V at which ionization starts. V is plotted against ν; the resulting curves should be linear, with a slope

$$dV/d\nu = h/e.$$

With V measured as V' int. volts, and ν as ν' cm^{-1}, we have

$$dV/d\nu = (pa10^8 dV')/(c^2 d\nu') = h/e$$

Lukirsky and Prilezaev use the metals Al, Zn, Sn, Ni, Cd, Cu, and Pt. Six curves, three with Zn, two with Al, and one with Ni, were the best. Unfortunately these investigators give no detailed data, and no indication of the actual equation used. Their final value of h is 6.543×10^{-27} erg · sec., the individual results being 6.539, 6.542, 6.540, 6.556, 6.536, and 6.546. We take

$$h = (6.543 \pm 0.010) \times 10^{-27} \text{ erg} \cdot \text{sec.}$$

These investigators estimate their final error in h as 0.1 to 0.2 per cent.

(e) *Wien's displacement law; Planck equation.*—h may be had from radiation constants in two different ways. The first is by means of c_2, in the Wien displacement law,

$$\lambda_{\max} T = c_2/\beta = A.$$

where $\beta = 4.9651$ (root of $e^{-\beta} + \beta/5 - 1 = 0$). The radiation constant c_2 occurs also in Planck's black-body radiation law in the form

$$c_2 = hc/k.$$

c = velocity of light, k (Boltzmann constant) $= R_0/N_0$, R_0 (gas constant per mole) $= \nu_n A_n/T_0$, and N_0 (Avogadro's number) $= Fc/e$. Substituting the values of ν_n, A_n, T_0, F and e previously adopted,

$$N_0 = (6.0644 \pm 0.0061) \times 10^{23} \text{ mole}^{-1}.$$
$$R_0 = (8.3136 \pm 0.0010) \times 10^7 \text{ erg} \cdot \text{deg.}^{-1} \cdot \text{mole}^{-1}.$$
$$k = (1.3709 \pm 0.0014) \times 10^{-16} \text{ erg} \cdot \text{deg.}^{-1}.$$

In 1919 Doctor Birge asked Coblentz what in his opinion was then the best value of c_2. He recommended 1.433 cm · deg.; this value was adopted. In a long critical review of the radiation constants, three years later, Coblentz [1] gives 1.432 as the most probable value. No probable error is given but the four results, obtained by four investigators, were 1.436, 1.430, 1.430 and 1.4318,

[1] Bur. Standards Bull., 17, 7, 1922.

the last being Coblentz' own value. Ladenburg[1] gives 1.432 ± 0.006. The separate results which he used are 1.425 to 1.441, 1.4295 ± 0.007, 1.435, 1.4318, 1.430. The chief error arises from the various corrections applied to the observed values. Coblentz' original value[2] of 1.4456 has become 1.4318 in his latest article,[3] Doctor Birge believes 0.003 is a much more reasonable estimate of error. Both Coblentz and Ladenburg agree on the absolute value. Hence he adopts

$$c_2 = 1.432 \pm 0.003 \text{ cm} \cdot \text{deg.}$$
$$h = (6.548 \pm 0.015) \times 10^{-27} \text{ erg} \cdot \text{sec.}$$

The radiation constant c_2 occurs in the Boltzmann factor $e^{-\epsilon/kT}$, (ϵ = energy, T = absolute temperature) in the form $e^{-c_2\nu/T} = e^{-c_2/\lambda T}$, where ν in cm^{-1}, or λ in cm, is the quantum equivalent of ϵ ergs.

(f) *The Stefan-Boltzmann law and the Planck equation.*—The second method for determining h by the radiation constants is through the Stefan-Boltzmann law, $E = \sigma T^4 = acT^4/4$. h is connected with σ, using Planck's law, by the relation

$$h = (2\pi^5 k^4 / 15 c^2 \sigma)^{\frac{1}{3}}.$$

As in the case of c_2, there is a difference of opinion concerning the accuracy with which σ may be measured. The best value, in 1919, was that obtained by Coblentz,[3] namely $(5.722 \pm 0.012) \times 10^{-5}$ erg · cm^{-2} · deg.$^{-4}$ · sec.$^{-1}$. In his more recent discussion, Coblentz[4] gives all available data, and concludes that the most probable value lies between 5.72 and 5.73.

Since this 1922 article by Coblentz, there have been two new determinations of σ, one by Hoffman[5] (method of Westphal), giving $\sigma = 5.764 \pm 0.052$, and the other by Kussman,[6] using the modified Ångström pyrheliometer. This latter method was used also by Coblentz[3] giving 5.722 as stated, by Gerlach[7] giving 5.80, and by Kahanowicz[8] giving 5.69 to 5.73 as corrected by Coblentz.[4] Kussman obtained $\sigma = 5.795 \pm$ one per cent. Ladenburg[1] quotes the four results by Gerlach, Hoffman, Coblentz, and Kussman. He adopts the *unweighted* mean. He agrees with Gerlach that Coblentz' true error is more nearly 0.06 than 0.012. The experimental results of Kussman[6] and Coblentz[3] are in almost perfect agreement. The discrepancy in their results is due to the correction for the lack of complete absorption of the receiver. Michel and Kussman[9] claim to prove that the correction Coblentz applied is too small. The values of σ by Kussman and by Hoffman, as well as Gerlach's earlier value of 5.80, correspond to impossibly low values of h. Coblentz' result gives an h in good agreement with that obtained by more accurate methods. This tends to indicate the correctness of Coblentz' correction for incomplete absorption, as opposed to Kussman's.

[1] H.P., 23, 303. [2] Bur. Standards Bull., 10, 1, 1914. [3] Proc. Nat. Acad. Sci., 3, 504, 1917. [4] Bur. Standards Bull., 17, 7, 1912. [5] Zeit. Phys., 14, 301, 1923. [6] Ibid., 25, 58, 1924. [7] Ann. Phys., 50, 259, 1916; Zeit. Phys., 2, 76, 1920. [8] Nuovo Cimento, 13, 142, 1917. [9] Zeit. Phys., 18, 263, 1923.

It appears that Coblentz' estimated error for his own work (5.722 ± 0.012) is too small, but that his final average of the work of all investigators up to 1922 (5.72 to 5.73) should be more trustworthy than any single value. We will choose 5.725 and 0.02 for its probable error. This result is then to be averaged with the more recent work whence

$$\sigma = (5.735 \pm 0.011) \times 10^{-5} \text{ erg} \cdot \text{cm}^{-2} \cdot \text{deg.}^{-4} \cdot \text{sec.}^{-1}$$

and

$$a = 4\sigma/c = (7.652 \pm 0.015) \times 10^{-15} \text{ erg} \cdot \text{cm}^{-3} \cdot \text{deg.}^{-4}$$

There has appeared a further determination of this quantity, by Hoare.[1] He used a Callendar radio balance; the advantage of the method is that both source and receiver are essentially "black-bodies." Hoare obtains $\sigma = 5.735$, agreeing exactly with the value adopted. He lists 38 separate results, average deviation only 0.016. The inclusion of this new result leaves the average value unchanged, and Doctor Birge leaves the probable error unchanged. Objection might be made to this adopted error as too small; such an objection can hardly hold in the face of Hoare's work. This new work also speaks against Strum's assumption of an inadequacy of Planck's formula. We have then

$$h = (6.539 \pm 0.010) \times 10^{-27} \text{ erg} \cdot \text{sec.}$$

(g) *Summary.*—We have now six determinations of h:

Rydberg constant	$h = 6.547 \pm 0.011$	Power of e involved, 5/3
Ionization potentials	6.560 ± 0.015	3/3
X rays	6.550 ± 0.009	4/3
Photoelectric	6.543 ± 0.010	3/3
c_2	6.548 ± 0.015	3/3
σ	6.539 ± 0.010	4/3

Doctor Birge adopts

$$\boldsymbol{h} = \mathbf{(6.547 \pm 0.008) \times 10^{-27}} \textbf{ erg} \cdot \textbf{sec.}$$

This value of h is identical with Ladenburg's most recent estimate.[2] This identity is spurious, since Ladenburg assumes $e = 4.774 \times 10^{-10}$. If this older value of e had been used in the present work, we should have obtained $h = 6.5535$, in practically exact agreement with Doctor Birge's 1919 value (6.5543).

Another potentially accurate method is given by the Compton shift of X-ray lines. The theoretical equation for this is $\Delta\lambda = (h/mc)(1 - \cos\phi)$, where m is the mass of an electron, as deduced from the values of e and e/m. Since h varies in value with e, this equation can better be used to evaluate e/m. We can in fact write $\Delta\lambda = (h/e)(e/m)(1 - \cos\phi)$ in which e as usual is in *es* units, and e/m in *em* units. Then

$$e/m = (\Delta\lambda)/(h/e)(1 - \cos\phi)$$

The most accurate work on this subject has been done by Sharp,[3] who obtains $\Delta\lambda = (0.04825 \pm 0.00017) \times 10^{-8}$ cm, for $(1 - \cos\phi) = (1.984 \pm 0.001)$. With the adopted values of h and e, we have $h/e = (1.3725 \pm 0.0005) \times 10^{-17}$

[1] Philos. Mag., 6, 828, 1928. [2] H.P., 23, 279. [3] Phys. Rev., 26, 691, 1925.

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erg · sec · es^{-1}. Substituting, one finds $e/m = (1.772 \pm 0.006) \times 10^7$ abs. *em* units, the final error being due almost entirely to the error in $\Delta\lambda$. It seems possibly significant that this value agrees better with the deflection than with the spectroscopic value of e/m, for the theory used in the derivation of the equation is essentially the collision theory of classical dynamics for free electrons.

e, e/m, and *h*[1] appear in many important constants. *h* depends for its value on *e*, therefore the *e* appears implicitly, if not explicitly, in every quantum relation. The outstanding discrepancy was between the work of Wagner and of Duane and co-workers, on the value of *h* from the X-ray continuous spectrum. The recent work of Feder, using this method, gives *h* in exact agreement with the value adopted, and explains Wagner's low value. Doctor Birge now feels that the value of h/e listed in Table 43 can be assumed with some confidence. The real problem concerns the values of *e* and of e/m.

The need of two values of e/m is very annoying, and fundamentally unsatisfactory. The same situation seems to be arising in regard to *e*. Millikan's value has been accepted; it was the only one available. The new work on X rays opened another possibility. The value of Bäcklin is one-half per cent higher than Doctor Birge's adopted value. As a final result Doctor Bearden obtains for the absolute wave length of the (unresolved) Cu $K\alpha$ line, 1.5439 ± 0.0002A, and for the Cu $K\beta$ line, 1.3940 ± 0.0002A. These results are obtained under many varied conditions. The first is 0.345 per cent higher than Siegbahn's value, the second 0.336 per cent. The *relative* wave lengths are in agreement with Siegbahn, but the *absolute* wave lengths lead to a value for calcite of $d'_{20} = 3.0398$A, and $e = 4.825 \times 10^{-10}$ abs. *es* units, 1.15 per cent above Doctor Birge's adopted value of *e*. It is desirable to consider the various relations that have been suggested between these constants. The most famous connects *e*, e/m, *h*, and *c* in Bohr's formula for the Rydberg constant. This was used to evaluate *h*, and the value (6.54713) is identical to four digits with that adopted. Hence, the indirectly calculated value of e/m is also practically identical with that adopted. Thus the *adopted* values of *e*, e/m, *h* and *c* form a self-consistent system, as judged by the Bohr formula for R_∞.

Lewis and Adams[2] (theory of ultimate rational units), have obtained, with the aid of Planck's radiation law, the relation: $hc/2\pi e^2 = 8\pi(8\pi^5/15)^{\frac{1}{3}}$. The right side equals 137.348; the left side, with the constants here adopted, equals $137.29_4 \pm 0.11$. The left side equals the reciprocal of the fine structure constant α, and the value quoted is taken directly from Table 43. The numerical agreement is very striking. The present agreement shows that this method yields a value of *h* almost identical with that adopted.

α is a dimensionless constant involving fundamental general constants; it should be remembered that to make α dimensionless, we must include with the factor *hc* the unknown dimensions of specific inductive capacity.

[1] Note added by Birge April, 1929 (abbreviated). [2] Phys. Rev., 3, 92, 1914.

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Perles[1] has pointed out that the ratio of the mass of the proton to that of the electron (M_p/m_0) is another dimensionless constant which should have some significance, and has found that

$$(hc/e^2)\,(=2\pi/\alpha)=(M_p/m_0)\,(\pi-1)$$

the left side equals 862.64 ± 0.68, the right 858.36 ± 0.49 or 862.26 ± 0.99 depending on whether one uses the spectroscopic or the deflection value of e/m. The agreement is good for the deflection value but poor for the spectroscopic.

Note.—In evaluating the constants, it has been necessary to calculate auxiliary constants, and also to use certain conventional quantities, such as g_{45} and g_n. All such quantities are listed in Table 42.

In addition to constants listed in Table 42 there are many other functions of constants given on page 103 of this table and in Table 42. A number of these derived constants are collected in Table 43. An attempt has been made to include the more important or more frequently used values. The process for obtaining the correct probable error for many of the constants of Tables 42 and 43 is sometimes involved. The various *derived* constants of Table 43 (and the occasional derived constant appearing on page 103 of this table and in Table 41) are given with one and often two more digits than required by the probable error. Such digits are printed below the line, and have been added that calculations made in different ways shall not introduce any appreciable error.

e/m always indicates merely the *ratio* of charge to mass for an electron, in *em* units; e indicates electronic charge in *es* units; m_0, electronic mass; m, the atomic weight of an electron. A more logical but less convenient nomenclature would have been (e/m_0) *es* units, and possibly (e'/m_0) *em* units.

In the quantum relation, $\epsilon=h\nu=eV$, each side represents energy in ergs, provided all quantities are in abs. c.g.s. units. ν/V $(=e/h)$ then measures the frequency in sec.$^{-1}$ associated with one abs. *es* unit of potential. It is usually convenient to substitute the wave number (ν') or the wave length (λ) in place of ν, and to substitute the number of abs. volts (V'') in place of V. $(V'=$ int. volts, throughout this paper). The values of the various ratios, such as ν'/V'' etc., are given in Table 43.

An electron which has fallen through one abs. volt of potential is termed an abs. volt-electron; its energy in ergs and speed in cm · sec.$^{-1}$ are given in Table 43. Corresponding to any *ionization potential* of an atom or molecule in volts (V''), there is an *energy of ionization* (eV'') which can be measured in units equal to the energy of a volt-electron, and is so designated. An ionization potential of 10 volts corresponds to an energy of ionization of 10 volt-electrons. Similarly, in the case of molecules, we speak of a *dissociation potential* of, let us say, 10 volts, and a corresponding energy of dissociation (heat of dissociation) of 10 volt-electrons per molecule. The factor by which this last quantity must be multiplied to give the heat of dissociation in calories per mole is given in Table 43. Unfortunately there has arisen the practise, to which Doctor Birge pleads guilty, of designating the *heat* of dissociation as 10 volts, instead of stating, more correctly, that the equivalent dissociation *potential* is 10 volts, or that the heat of dissociation per molecule is 10 volt-electrons.

The name of the units conforms as far as possible with current practise. Difficulties arise with the unknown dimensions of magnetic permeability μ, and specific inductive capacity ϵ. It is customary to indicate these unknown dimensions by the symbols μ and ϵ. A given unit, such as the gauss, is applied only to quantities of a given set of dimensions, *including* μ and ϵ. In the present discussion we are concerned only with numerical magnitudes and no particular attention has accordingly been paid to this matter of dimensions.

[1] Naturwiss., 16, 1094, 1928.

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Thus the statement that the absolute *em* unit of resistance is one cm · $sec.^{-1}$ involves the assumption not only of unit permeability, but also of dimensionless permeability. In a number of the equations given in Table 43 the two sides of the equation do *not* check dimensionally unless one assumes μ and ϵ to be dimensionless. It follows from this that the name of the unit stated in the table applies strictly only to one side of such an equation. In such cases the unit applies to the left side of the equation, since this is the quantity being evaluated. The right side gives merely the most direct derivation of the numerical magnitude, in terms of quantities already evaluated. Since this ambiguity does not affect the numerical magnitude, it is inconsequential in the present discussion. As examples of this situation we cite the fine structure constant α, which is dimensionless. To satisfy this condition one should write $\alpha = 2\pi e^2/\epsilon_0 hc$ where ϵ_0 is numerically unity, and represents merely the dimesions of ϵ. The ratio of the Bohr magneton μ_1 to the Bohr unit of angular momentum $(h/2\pi)$ is strictly $\mu_0 \frac{1}{2}(e/m)$, where μ_0 is numerically unity, and represents merely the dimensions of permeability.

The mole is a (variable) unit of mass, equal to the molecular weight in grams. The gram equivalent is a similar (variable) unit of mass, equal to the atomic or molecular weight in grams, divided by the valence.

The various quantities appearing on page 103 of this table and in Table 42 have been discussed. No general explanation will be given of the meaning or use of the quantities appearing in Table 43; any adequate explanation would constitute a textbook of modern physics and physical chemistry. For the more specialized constants, no explanation is needed by investigators working with such constants, and it is to such persons that the data will be most useful.

In conclusion, attention should be directed merely to two constants for which the formula used here differs from that normally given. It is customary to use for the speed of the electron in the normal orbit of hydrogen, as given by Bohr's original theory, a value which refers to the nucleus considered as the center of coordinates. This is called $v_0 (= \alpha c)$ in Table 43. It would seem more logical to give the speed referred to the center of mass, the quantity denoted v_0' in Table 43. There is a similar discrepancy in the case of the radius of this orbit. The electron, according to Bohr, moves about the center of mass in a circle of radius a_0', as it is denoted in Table 43. This is not the same as the constant separation of the nucleus and electron, which is here denoted a_0. In the literature these two quantities, a_0, and a_0', are sometimes confused. The expressions for v_0, v_0', a_0, and a_0' given in Table 43 include also the factor $(1 - \alpha^2)^{1/2}$, arising from the variation of mass with speed.

Birge. Probable values of e, h, e/m and α Phys. Rev. 40, 228, 1932.

e, $(4.7688 \pm 0.0040) \times 10^{-10}$ *es* units
h, $(6.5443 \pm 0.0091) \times 10^{-27}$ erg · sec.
e/m, $(1.7611 \pm 0.0009) \times 10^{7}$ *em* units · g^{-1}
$1/\alpha$, 137.307 ± 0.048

Fundamental constants, Birge.—The critical discussion of the determination by Dr. R. T. Birge of theses values will be found in abbreviated form on pages 73 to 102 of this book; for full details see Phys. Rev. Suppl., 1, 1, 1929. These constants, for purposes of computation, are to be taken as exactly correct; that is, all additional digits in each constant are to be assumed as zero. The real probable error of each value is of course that indicated in the table, and each constant has an accepted value carried only to the number of significant figures required by the adopted probable error.

Velocity of light .... $c = (2.99796 \pm 0.00004) \times 10^{10}$ cm · sec.$^{-1}$
Gravitation constant .... $G = (6.664 \pm 0.002) \times 10^{-8}$ dyne · cm^2 · g^{-2}
Liter .... $l = 1000.027 \pm 0.001$ cm^3
Volume of perfect gas (0°C, A_n) .. $v_n = (22.4141 \pm 0.0008) \times 10^3$ cm^3 · mole^{-1}
Volume of perfect gas (0°C, A_{45}) ... $R = 22.4146 \pm 0.0008$ liter · mole^{-1}
International ohm $= p$ abs. ohm .... $p = 1.00051 \pm 0.00002$
International ampere $= q$ abs. amp. .. $q = 0.99995 \pm 0.00005$
Normal atmosphere .... $A_n = (1.013249 \pm 0.000003) \times 10^6$ dyne · cm^{-2}
45° atmosphere .... $A_{45} = (1.013199 \pm 0.000003) \times 10^6$ dyne · cm^{-2}
Ice point (absolute scale) .... $T_0 = 273.18 \pm 0.03$°K.
Mechanical equivalent of heat ..... $J_{15} = 4.1852 \pm 0.0006$ abs. joule · cal.$_{15}^{-1}$
Electrical equivalent of heat ...... $J'_{15} = 4.1835 \pm 0.0007$ int. joule · cal.$_{15}^{-1}$
Faraday constant .... $F = 96494 \pm 5$ int. coul. · g-equiv.$^{-1}$
$= 96489 \pm 7$ abs. coul. · g-equiv.$^{-1}$
$= 9648.9 \pm 0.7$ abs. *em*-unit · g-equiv.$^{-1}$
$Fc = (2.8927_0 \pm 0.0002) \times 10^{14}$ abs. *es*-unit · g-equiv.$^{-1}$
Electronic charge * .... $e = (4.770 \pm 0.005) \times 10^{-10}$ abs. *es*-units
$e/c = (1.5910_8 \pm 0.0016) \times 10^{-20}$ abs. *em*-units
Specific electronic charge (spectroscopic) .... $e/m = (1.761 \pm 0.001) \times 10^7$ abs. *em*-unit · g^{-1}
$(e/m)c = (5.279_{41} \pm 0.003) \times 10^{17}$ abs. *es*-unit · g^{-1}
Specific electronic charge (deflection) .... $e/m = (1.769 \pm 0.002) \times 10^7$ abs. *em*-unit · g^{-1}
$(e/m)c = (5.303_{39} \pm 0.006) \times 10^{17}$ abs. *es*-unit · g^{-1}
Planck constant * .... $h = (6.547 \pm 0.008) \times 10^{-27}$ erg · sec.

Atomic weights

O = 16.0000	C = 12.003 ± 0.001	I = 126.932 ± 0.002
He = 4.0022 ± 0.0004	H = 1.00777 ± 0.00002	Ca = 40.075 ± 0.005
Ag = 107.880 ± 0.001	N = 14.0083 ± 0.0008	

TABLE 41.—Powers of c, h, e, h/c

c^{-2};	$(1.11262 \pm 0.00003) 10^{-21}$ cm^{-2} · sec.^{2}	h^{-3};	$(3.563_{47} \pm 0.012) 10^{78}$ erg^{-3} · sec.$^{-3}$
c^{-1};	$(3.33560 \pm .00005) 10^{-11}$ cm^{-1} · sec.	h^{-2};	$(2.333_{00} \pm .005) 10^{52}$ erg^{-2} · sec.$^{-2}$
$c^{-1/2}$;	$(5.77546 \pm .00006) 10^{-6}$ cm$^{-1/2}$ · sec.$^{1/2}$	h^2;	$(4.286_{32} \pm .010) 10^{-53}$ erg^2 · sec.^{2}
$c^{1/2}$;	$(1.73146 \pm .00001) 10^5$ cm$^{1/2}$ · sec.$^{-1/2}$	h^3;	$(2.806_{25} \pm .010) 10^{-79}$ erg^3 · sec.^{3}
c^2;	$(8.98782 \pm .00024) 10^{20}$ cm^2 · sec.$^{-2}$	e^{-2};	$(4.395_{04} \pm .009) 10^{18}$ *es*-units^{-2}
c^3;	$(2.69449 \pm .00011) 10^{31}$ cm^3 · sec.$^{-3}$	e^2;	$(2.2752_9 \pm .0045) 10^{-19}$ *es*-units^2
c^4;	$(8.07798 \pm .00043) 10^{41}$ cm^4 · sec.$^{-4}$	e^3;	$(1.0853_{13} \pm .0033) 10^{-28}$ *es*-units^3
		e^4;	$(5.176_{94} \pm .021) 10^{-38}$ *es*-units^4
h/c;	$(2.183_{51} \pm .003) 10^{-37}$ g·cm	e^5;	$(2.469_{40} \pm .012) 10^{-47}$ *es*-units^5

* Millikan, Phys. Rev., 35, 1930, takes $e = 4.774 \times 10^{-10}$, $h = 6.547 \times 10^{-27}$, $N = 6.062 \times 10^{-23}$.

Table 42

ADDITIONAL PHYSICAL CONSTANTS

Used or evaluated by Doctor Birge in Phys. Rev. Suppl., 1, 1, 1929, in connection with Table 40, p. 103.

Ratio of *es* to *em* units (direct)...... $c' = (2.9979 \pm 0.0001) \times 10^{10}$ cm · sec.$^{-1}$
Acceleration of gravity (45°)....... $g_{45} = 980.616$ cm · sec.$^{-2}$
Acceleration of gravity (normal)... $g_n = 980.665$ cm · sec.$^{-2}$
Mean density of the earth........... $\delta = 5.522 \pm 0.002$ g · cm^{-2}

Maximum density of water... $\delta_m(H_2O) = 0.999973 \pm 0.000001$ g · cm^{-3}
Density of oxygen gas (0°C, A_{45})
$L(O_2) = 1.428965 \pm 0.000030$ g · liter^{-1}
Factor converting oxygen (0°C, A_{45}) to ideal gas .... $1 - \alpha(O_2) = 1.000927 \pm 0.000030$
Density of nitrogen (0°C, A_{45}). $L(N_2) = 1.25046 \pm 0.000045$ g · liter^{-1}
Factor converting nitrogen (0°C, A_{45}) to ideal gas.............. $1 - \alpha(N_2) = 1.00043 \pm 0.00002$
Density of Hg (0°C, A_n)......... $D_n = 13.59509 \pm 0.00003$ g · cm^{-3}
International volt (= pq abs. volts).. $pq = 1.00046 \pm 0.00005$
International joule (= pq^2 abs. joules)
$pq^2 = 1.00041 \pm 0.00010$
Electrochemical equivalent of Ag
$E(Ag) = (1.11800 \pm 0.00005) \times 10^{-3}$ g · int. coul.$^{-1}$
$= (1.11805 \pm 0.00007) \times 10^{-3}$ g · abs. coul.$^{-1}$
Density of calcite (20°C).......... $\rho = 2.7102 \pm 0.0004$ g · cm^{-3}
Structural constant of calcite (20°C)
$\phi(\beta) = 1.09630 \pm 0.00007$

True grating space of calcite (20°C)
$d'_{20} = (3.0283 \pm 0.0010) \times 10^{-8}$ cm
Effective grating space of calcite (20°C) .... $d_{20} = (3.0279 \pm 0.0010) \times 10^{-8}$ cm

Rydberg constant for hydrogen...... $R_H = 109677.759 \pm 0.05$ cm^{-1}
Rydberg constant for ionized helium
$R_{He} = 109722.403 \pm 0.05$ cm^{-1}
Wave length of red Cd line (15°C, A_n)
$\lambda_{Cd} = 6438.4696$ I.A. (definition of I.A. unit)
Rydberg constant for infinite mass.. $R_\infty = 109737.42 \pm 0.06$ cm^{-1}
$cR_\infty = (3.28988 \pm 0.00004) \times 10^{15}$ sec.$^{-1}$
Avogadro's number .... $N_0 = Fc/e = (6.064_{36} \pm 0.006) \times 10^{23}$ mole^{-1}
Gas constant per mole... $R_0 = \nu_n A_n / T_0 = (8.3136_0 \pm 0.0010) \times 10^7$ erg · degree^{-1} · mole^{-1}
$R'_0 = R_0/(J_{15} \times 10^7) = 1.9864_3 \pm 0.0004$ cal.$_{15}$ · deg.$^{-1}$ · mole^{-1}
Boltzmann constant .... $k = R_0/N_0 = (1.3708_9 \pm 0.0014) \times 10^{-16}$ erg · deg.$^{-1}$
Second radiation constant (exp. value)
$c_2 = 1.432 \pm 0.003$ cm · deg.
Second radiation constant (indirect)
$c_2 = hc/k = 1.4317_4 \pm 0.0006$ cm · deg.

Radiation density constant.... $a = 4\sigma/c = (7.651_8 \pm 0.015) \times 10^{-15}$ erg · cm^{-3} · deg.$^{-4}$

Stefan-Boltzmann constant (exp. value)
$\sigma = (5.735 \pm 0.011) \times 10^{-5}$ erg · cm^{-2} · deg.$^{-4}$ · sec.$^{-1}$
Stefan-Boltzmann constant (indirect)
$\sigma = 2\pi^5 k^4 / 15 c^2 h^3 = (5.713_9 \pm 0.006) \times 10^{-5}$ erg · cm^{-2} · deg.$^{-4}$ · sec.$^{-1}$

Table 43

MISCELLANEOUS DERIVED PHYSICAL CONSTANTS

Evaluated by Doctor Birge in Phys. Rev. Suppl., 1, 1, 1929.

(See notes on page 99.)

Mass of electron (spectroscopic)

$$m_0 = e/\{c(e/m)_{sp}\} = (9.035_{10} \pm 0.010) \times 10^{-28}\ \text{g}$$

Mass of electron (deflection)

$$m_0 = e/\{c(e/m)_{defl}\} = (8.994_{25} \pm 0.014) \times 10^{-28}\ \text{g}$$

Atomic weight of electron (spectroscopic)

$$m = F/(e/m)_{sp} = (5.479_{22} \pm 0.003) \times 10^{-4}$$

Atomic weight of electron (deflection)

$$m = F/(e/m)_{defl} = (5.454_{44} \pm 0.006) \times 10^{-4}$$

Mass of atom of unit atomic weight

$$M_0 = 1/N_0 = (1.6489_8 \pm 0.0016) \times 10^{-24}\ \text{g}$$

Mass of hydrogen atom........ $M_H = H/N_0 = (1.6617_9 \pm 0.0017) \times 10^{-24}$ g

Number of atoms per gram of hydrogen

$$1/M_H = (6.017_{61} \pm 0.006) \times 10^{23}\ \text{g}^{-1}$$

Mass of proton......... $M_P = (H - m)/N_0 = (1.6608_9 \pm 0.0017) \times 10^{-24}$ g

Mass of α particle.... $M\alpha = (He - 2m)/N_0 = (6.597_{74} \pm 0.007) \times 10^{-24}$ g

Charge (electrolysis) of 1 g hydrogen

$$e/M_H = F/H = (9574.5_1 \pm 0.7)\ \text{abs. } em\text{-units} \cdot \text{g}^{-1}$$

Specific charge of proton

$$e/M_P = F/(H - m) = (9579.7_3 \pm 0.7)\ \text{abs. } em\text{-units} \cdot \text{g}^{-1}$$

Specific charge of α particle

$$2e/M\alpha = 2F/(He - 2m) = (4823.1_1 \pm 0.6)\ \text{abs. } em\text{-units} \cdot \text{g}^{-1}$$

Ratio, mass H atom to mass electron (spectroscopic) .... $(e/m)_{sp}/(e/M_H) = 1839._{26} \pm 1$

Ratio, mass H atom to mass electron (deflection) .... $(e/m)_{defl}/(e/M_H) = 1847._{61} \pm 2$

Ratio, mass proton to mass electron (spectroscopic) .... $M_P/m_{sp} = 1839.26 - 1 = 1838._{26} \pm 1$

Ratio, mass proton to mass electron (deflection) .... $M_P/m_{defl} = 1847.61 - 1 = 1846._{61} \pm 2$

Energy associated with unit wave number

$$\epsilon/\nu' = hc = (1.9627_{64} \pm 0.0025) \times 10^{-16}\ \text{erg} \cdot \text{cm}$$

Potential (es) associated with unit frequency

$$V/\nu = h/e = (1.3725_4 \pm 0.0005) \times 10^{-17}\ es\text{-units} \cdot \text{sec.}$$

Frequency associated with 1 abs. volt

$$\nu/V'' = 10^8 e/hc = (2.4302_5 \pm 0.0009) \times 10^{14}\ \text{sec.}^{-1} \cdot \text{abs. volt}^{-1}$$

Wave number associated with 1 abs. volt

$$\nu_0 = \nu'/V'' = 10^8 e/hc^2 = (8106._{31} \pm 3)\ \text{cm}^{-1} \cdot \text{abs. volt}^{-1}$$

Wave length associated with 1 abs. volt

$$\lambda_0 = \lambda V'' = hc^2/e = (12336._1 \pm 5) \times 10^{-8}\ \text{cm} \cdot \text{abs. volt}$$

MISCELLANEOUS DERIVED PHYSICAL CONSTANTS

Energy of one-abs.-volt-electron
$h\nu/V'' = 10^8 e/c = (1.5910_8 \pm 0.0016) \times 10^{-12}$ ergs

Speed of abs.-volt-electron (spectroscopic)
$v_e = [2 \times 10^8 (e/m)_{sp}]^{1/2} = (5.9346_4 \pm 0.0017) \times 10^7$ cm · sec.$^{-1}$

Speed of abs.-volt-electron (deflection)
$v_e = [2 \times 10^8 (e/m)_{defl}]^{1/2} = (5.9481_1 \pm 0.0034) \times 10^7$ cm · sec.$^{-1}$

Fine structure constant............$\alpha = 2\pi e^2/hc = 7.283_{04} \pm 0.006) \times 10^{-3}$

Reciprocal of fine structure constant........$1/\alpha = 137.29_4 \pm 0.11$

Magnetic moment, Bohr magneton (spectroscopic)................$\mu_1 = \{h(e/m)_{sp}\}/4\pi = (0.9174_{70} \pm 0.0013) \times 10^{-20}$ erg · gauss^{-1}

Magnetic moment, Bohr magneton (deflection)
$\mu_1 = \{h(e/m)_{defl}\}/4\pi = (0.9216_{38} \pm 0.0016) \times 10^{-20}$ erg · gauss^{-1}

Magnetic moment per mole (1 Bohr magneton per molecule) (spectroscopic)..........$\mu_1 N_0 = 5563_{.57} \pm 10$ erg · gauss^{-1} · mole^{-1}

Magnetic moment per mole (1 Bohr magneton per molecule) (deflection)..............$\mu_1 N_0 = 5589_{.14} \pm 11$ erg · gauss^{-1} · mole^{-1}

Zeeman displacement per gauss
$\Delta\nu'/H = (e/m)_{sp}/4\pi c = (4.674_{38} \pm 0.003) \times 10^{-5}$ cm^{-1} · gauss^{-1}

Band spectrum constant connecting wave-number (cm^{-1}) and moment of inertia.........$h/8\pi^2 c = (27.65_{83} \pm 0.04) \times 10^{-40}$ g · cm

Atomic specific heat constant.......$c_2/c = h/k = (4.7757_3 \pm 0.0019) \times 10^{-11}$ sec · deg.

Reduced mass of H atom...$\mu_H = R_H (m_0)_{sp}/R_\infty = 9.030_{19} \pm 0.010) \times 10^{-28}$ g

Schroedinger constant for H atom.....$8\pi^2 \mu_H/h^2 = (1.663_{12} \pm 0.003) \times 10^{27}$ g · erg^{-2} · sec.$^{-2}$

Schroedinger constant for electron
$8\pi^2 (m_0)_{sp}/h^2 = (1.664_{32} \pm 0.003) \times 10^{27}$ g · erg^{-2} · sec.$^{-2}$

Ionization potential for H atom..........$R_H/\nu_0 = 13.529_9 \pm 0.005$ abs. volt

Ionization potential for He$^+$............$4R_{He}/\nu_0 = 54.141_7 \pm 0.020$ abs. volt

Radius of Bohr orbit in normal hydrogen, referred to center of mass, using experimental value of R_∞........$a_0' = \alpha(1 - \alpha^2)^{1/2}/4\pi R_\infty = (0.5281_{69} \pm 0.0004) \times 10^{-8}$ cm

Speed of electron in normal H orbit, referred to center of mass................$v_0 = \alpha c R_H/R_\infty = (2.1824_2 \pm 0.0017) \times 10^8$ cm · sec.$^{-1}$

MISCELLANEOUS DERIVED PHYSICAL CONSTANTS

Hydrogen doublet constant

$$\Delta\nu_H = R_H\alpha^2/16 = 0.3636_{59} \pm 0.0006 \text{ cm}^{-1}$$

Compton shift at 90° (spectroscopic)

$$h/m_0c = (e/m)_{sp}h/e = (0.024170_4 \pm 0.000016) \times 10^{-8} \text{ cm}$$

Compton shift at 90° (deflection)

$$h/m_0c = (e/m)_{defl}h/e = (0.02428_{02} \pm 0.00003) \times 10^{-8} \text{ cm}$$

Wave length of 1-abs.-volt-electron

$$h/[m_0(ve)_{sp}] = (12.210_0 \pm 0.006) \times 10^{-8} \text{ cm}$$

Loschmidt number ....$n_0 = N_0/v_n = (2.705_{60} \pm 0.003) \times 10^{19} \text{ cm}^{-3}$ (0°C, A_n)

Wien's displacement constant (indirect)

$$A = c_2/4.9651 = 0.28836_1 \pm 0.00011 \text{ cm} \cdot \text{deg.}$$

First radiation constant *............$c_1 = 8\pi hc = (4.932_{06} \pm 0.006) \times 10^{-15} \text{ erg} \cdot \text{cm}$

or $hc^2 = (0.5884_{29} \pm 0.0008) \times 10^{-5} \text{ erg} \cdot \text{cm}^2 \cdot \text{sec.}^{-1}$

or $2\pi hc^2 = (3.697_{20} \pm 0.005) \times 10^{-5} \text{ erg} \cdot \text{cm}^2 \cdot \text{sec.}^{-1}$

Energy per mole, equivalent to 1-abs. -volt-electron per molecule

$$F(\text{abs. coul.} \cdot \text{g-equiv.}^{-1}) / J_{15}(\text{abs. joule} \cdot \text{cal.}_{15}^{-1}) = 23054._8 \pm 4 \text{ cal.}_{15} \cdot \text{mole}^{-1}$$

Sackur-Tetrode constant (ϵ = base of log. = 2.71828)

$$S_0 = R_0'\ln[(2\pi k)^{3/2}\epsilon^{5/2}/h^3N_0^{5/2}] = -11.0533 \pm 0.0026 \text{ cal.}_{15} \cdot \text{deg.}^{-1} \cdot \text{mole}^{-1}$$

Chemical constant (unit at. wt., pressure in atm.)

$$i_0' = \tfrac{3}{2}\log[2\pi k^{5/3}/N_0h^2] - \log A_n = -1.5882_5 \pm 0.0004$$

Multiplier of (Curie constant)$^{1/2}$ to give magnetic moment in Bohr magnetons per molecule ....$(3k/N_0)^{1/2}/\mu_1 = 2.8384_2 \pm 0.0019 \text{ erg}^{-1/2} \cdot \text{gauss} \cdot \text{deg.}^{-1/2} \cdot \text{mole}^{1/2}$

* $E_\lambda = c_1\lambda^{-5}(e^{-c_2/\lambda T} - 1)^{-1}$; E_λ may be defined in various ways, and c_1 varies accordingly. If $E_\lambda d\lambda$ denotes the energy density of unpolarized radiation in range $d\lambda$, $c_1 = 8\pi hc$. If $E_\lambda d\lambda$ denotes the intensity of emission of linearly polarized radiation in range $d\lambda$, perpendicular to a surface, per unit of surface, per unit solid angle, $c_1 = hc^2$. If $E_\lambda d\lambda$ denotes the emission of unpolarized radiation in range $d\lambda$, per unit surface, in all directions (2π solid angle), $c_1 = 2\pi hc^2$.

Table 44

VOLUME OF A GLASS VESSEL FROM THE WEIGHT OF ITS EQUIVALENT VOLUME OF MERCURY OR WATER

If a glass vessel contains at t° C, P grammes of mercury, weighed with brass weights in air at 760 mm pressure, then its volume in ccm

at the same temperature, t, : $V = PR \;= P\frac{p}{d}$,

at another temperature, t_1, : $V = PR_1 = Pp/d\,\{1 + \gamma\,(t_1 - t)\}$

p = the weight, reduced to vacuum, of the mass of mercury or water which, weighed with brass weights, equals 1 gram;

d = the density of mercury or water at t° C,

and $\gamma = 0.000\,025$, is the cubical expansion coefficient of glass.

Temperature t	WATER.			MERCURY.		
	R.	R_1, $t_1 = 10^\circ$.	R_1, $t_1 = 20^\circ$.	R.	R_1, $t_1 = 10^\circ$.	R_1, $t_1 = 20^\circ$.
0°	1.001192	1.001443	1.001693	0.0735499	0.0735683	0.0735867
1	1133	1358	1609	5633	5798	5982
2	1092	1292	1542	5766	5914	6098
3	1068	1243	1493	5900	6029	6213
4	1060	1210	1460	6033	6144	6328
5	1068	1193	1443	6167	6259	6443
6	1.001092	1.001192	1.001442	0.0736301	0.0736374	0.0736558
7	1131	1206	1456	6434	6490	6674
8	1184	1234	1485	6568	6605	6789
9	1252	1277	1527	6702	6720	6904
10	1333	1333	1584	6835	6835	7020
11	1.001428	1.001403	1.001653	0.0736969	0.0736951	0.0737135
12	1536	1486	1736	7103	7066	7250
13	1657	1582	1832	7236	7181	7365
14	1790	1690	1940	7370	7297	7481
15	1935	1810	2060	7504	7412	7596
16	1.002092	1.001942	1.002193	0.0737637	0.0737527	0.0737711
17	2261	2086	2337	7771	7642	7826
18	2441	2241	2491	7905	7757	7941
19	2633	2407	2658	8039	7872	8057
20	2835	2584	2835	8172	7988	8172
21	1.003048	1.002772	1.003023	0.0738306	0.0738103	0.0738288
22	3271	2970	3220	8440	8218	8403
23	3504	3178	3429	8573	8333	8518
24	3748	3396	3647	8707	8449	8633
25	4001	3624	3875	8841	8564	8748
26	1.004264	1.003862	1.004113	0.0738974	0.0738679	0.0738864
27	4537	4110	4361	9108	8794	8979
28	4818	4366	4616	9242	8910	9094
29	5110	4632	4884	9376	9025	9210
30	5410	4908	5159	9510	9140	9325

Taken from Landolt, Börnstein, and Meyerhoffer's Physikalisch-Chemische Tabellen.

TABLE 45.—Reductions of Weighings in Air to Vacuo

When the weight M in grams of a body is determined in air, a correction is necessary for the buoyancy of the air equal to $M\,\delta\,(1/d - 1/d_1)$ where δ = the density (wt. of 1 ccm in grams = 0.0012) of the air during the weighing, d the density of the body, d_1 that of the weights. δ for various barometric values and humidities may be determined from Tables 128 to 130. The following table is computed for $\delta = 0.0012$. The corrected weight $= M + kM/1000$.

Density of body weighed d.	Correction factor, k.			Density of body weighed d.	Correction factor, k.		
	Pt. Ir. weights $d_1 = 21.5$.	Brass weights 8.4.	Quartz or Al. weights 2.65.		Pt. Ir. weights $d_1 = 21.5$.	Brass weights 8.4.	Quartz or Al. weights 2.65.
.5	+ 2.34	+ 2.26	+ 1.95	1.6	+ 0.69	+ 0.61	+ 0.30
.6	+ 1.91	+ 1.86	+ 1.55	1.7	+ .65	+ .56	+ .25
.7	+ 1.66	+ 1.57	+ 1.26	1.8	+ .62	+ .52	+ .21
.75	+ 1.55	+ 1.46	+ 1.15	1.9	+ .58	+ .49	+ .18
.80	+ 1.44	+ 1.36	+ 1.05	2.0	+ .54	+ .46	+ .15
.85	+ 1.36	+ 1.27	+ 0.96	2.5	+ .43	+ .34	+ .03
.90	+ 1.28	+ 1.19	+ .88	3.0	+ .34	+ .26	− .05
.95	+ 1.21	+ 1.12	+ .81	4.0	+ .24	+ .16	− .15
1.00	+ 1.14	+ 1.06	+ .75	6.0	+ .14	+ .06	− .25
1.1	+ 1.04	+ 0.95	+ .64	8.0	+ .09	+ .01	− .30
1.2	+ 0.94	+ .86	+ .55	10.0	+ .06	− .02	− .33
1.3	+ .87	+ .78	+ .47	15.0	+ .03	− .06	− .37
1.4	+ .80	+ .71	+ .40	20.0	+ .004	− .08	− .39
1.5	+ .75	+ .66	+ .35	22.0	− .001	− .09	− .40

TABLE 46.—Reductions of Densities in Air to Vacuo

(This correction may be accomplished through the use of the above table for each separate weighing.)

If s is the density of the substance as calculated from the uncorrected weights, S its true density, and L the true density of the liquid used, then the vacuum correction to be applied to the uncorrected density, s, is $0.0012\,(1 - s/L)$.

Let W_s = uncorrected weight of substance, W_l = uncorrected weight of the liquid displaced by the substance, then by definition, $s = LW_s/W_l$. Assuming D to be the density of the balance of weights, $W_s\left\{1 + 0.0012\,(1/S - 1/D)\right\}$ and $W_l\left\{1 + 0.0012\,(1/L - 1/D)\right\}$ are the true weights of the substance and liquid respectively (assuming that the weighings are made under normal atmospheric corrections, so that the weight of 1 cc of air is 0.0012 gram).

Then the true density $S = \dfrac{W_s\left\{1 + 0.0012\,(1/S - 1/D)\right\}}{W_l\left\{1 + 0.0012\,(1/L - 1/D)\right\}}\,L.$

But from above $W_s/W_l = s/L$, and since L is always large compared with 0.0012,

$$S - s = 0.0012\,(1 - s/L).$$

The values of $0.0012\,(1 - s/L)$ for densities up to 20 and for liquids of density 1 (water), 0.852 (xylene) and 13.55 (mercury) follow:

(See reference below for discussion of density determinations).

Density of substance s.	Corrections.			Density of substance s	Corrections.	
	L = 1 Water.	L = 0.852 Xylene.	L = 13.55 Mercury.		L = 1 Water.	L = 13.55 Mercury.
0.8	+ 0.00024	–	–	11.	− 0.0120	+ 0.0002
0.9	+ .00012	–	–	12.	− .0132	+ .0001
1.	0.0000	− 0.0002	+ 0.0011	13.	− .0144	0.0000
2.	− .0012	− .0016	+ .0010	14.	− .0156	0.0000
3.	− .0024	− .0030	+ .0009	15.	− .0168	− .0001
4.	− .0036	− .0044	+ .0008	16.	− .0180	− .0002
5.	− .0048	− .0058	+ .0008	17.	− .0192	− .0003
6.	− .0060	− .0073	+ .0007	18.	− .0204	− .0004
7.	− .0072	− .0087	+ .0006	19.	− .0216	− .0005
8.	− .0084	− .0101	+ .0005	20.	− .0228	− .0006
9.	− .0096	− .0115	+ .0004			
10.	− .0108	− .0129	+ .0003			

Johnston and Adams, J. Am. Chem. Soc. 34, p. 563, 1912.

Table 47

MECHANICAL PROPERTIES: INTRODUCTION AND DEFINITIONS

(Compiled from various sources by Harvey A. Anderson, C.E., Assistant Engineer Physicist, U. S. Bureau of Standards.)

The mechanical properties of most materials vary between wide limits; the following figures are given as being representative rather than what may be expected from an individual sample. Figures denoting such properties are commonly given either as specification or experimental values. Unless otherwise shown, the values below are experimental. Credit for information included is due the U. S. Bureau of Standards; the Am. Soc. for Testing Materials; the Soc. of Automotive Eng.; the Motor Transport Corps, U. S. War Dept.; the Inst. of Mech. Eng.; the Inst. of Metals; Forest Products Lab.; Dept. of Agriculture (Bull. 556); Moore's Materials of Engineering; Hatfield's Cast Iron; and various other American, English and French authorities.

The specified properties shown are indicated minimums as prescribed by the Am. Soc. for Testing Materials, U. S. Navy Dept., Panama Canal, Soc. of Automotive Eng., or Intern. Aircraft Standards Board. In the majority of cases, specifications show a range for chemical constituents and the average value only of this range is quoted. Corresponding average values are in general given for mechanical properties. In general, tensile test specimens were 12.8 mm (0.505 in.) diameter and 50.8 mm (2 in.) gage length. Sizes of compressive and transverse specimens are generally shown accompanying the data.

All data shown in these tables are as determined at ordinary room temperature, averaging 20° C (68° F.). The properties of most metals and alloys vary considerably from the values shown when the tests are conducted at higher or lower temperatures.

The following definitions govern the more commonly confused terms shown in the tables. In all cases the stress referred to in the definitions is equal to the total load at that stage of the test divided by the original cross-sectional area of the specimen (or the corresponding stress in the extreme fiber as computed from the flexure formula for transverse tests).

Proportional Limit (abbreviated P-limit). — Stress at which the deformation (or deflection) ceases to be proportional to the load (determined with extensometer for tension, compressometer for compression and deflectometer for transverse tests).

Elastic Limit. — Stress which produces a permanent elongation (or shortening) of 0.001 per cent of the gage length, as shown by an instrument capable of this degree of precision (determined from set readings with extensometer or compressometer). In transverse tests the extreme fiber stress at an appreciable permanent deflection.

Yield Point. — Stress at which marked increase in deformation (or deflection) of specimen occurs without increase in load (determined usually by drop of beam or with dividers for tension, compression or transverse tests).

Ultimate Strength in Tension or Compression. — Maximum stress developed in the material during test.

Modulus of Rupture. — Maximum stress in the extreme fiber of a beam tested to rupture, as computed by the empirical application of the flexure formula to stresses above the transverse proportional limit.

Modulus of Elasticity (Young's Modulus). — Ratio of stress within the proportional limit to the corresponding strain, — as determined with an extensometer. Note: All moduli shown are obtained from tensile tests of materials, unless otherwise stated.

Brinell Hardness Numeral (abbreviated B. h. n.). — Ratio of pressure on a sphere used to indent the material to be tested to the area of the spherical indentation produced. The standard sphere used is a 10-mm diameter hardened steel ball. The pressures used are 3000 kg for steel and 500 kg for softer metals, and the time of application of pressure is 30 seconds. Values shown in the tables are based on spherical areas computed in the main from measurements of the diameters of the spherical indentations, by the following formula:

$$\text{B. h. n.} = P \div \pi t D = P \div \pi D(D/2 - \sqrt{D^2/4 - d^2/4}).$$

P = pressure in kg, t = depth of indentation, D = diameter of ball, and d = diameter of indentation, — all lengths being expressed in mm. Brinell hardness values have a direct relation to tensile strength, and hardness determinations may be used to define tensile strengths by employing the proper conversion factor for the material under consideration.

Shore Scleroscope Hardness. — Height of rebound of diamond pointed hammer falling by its own weight on the object. The hardness is measured on an empirical scale on which the average hardness of martensitic high carbon steel equals 100. On very soft metals a "magnifier" hammer is used in place of the commonly used "universal" hammer and values may be converted to the corresponding "universal" value by multiplying the reading by $\frac{4}{7}$. The scleroscope hardness, when accurately determined, is an index of the tensile elastic limit of the metal tested.

Erichsen Value. — Index of forming quality of sheet metal. The test is conducted by supporting the sheet on a circular ring and deforming it at the center of the ring by a spherical pointed tool. The depth of impression (or cup) in mm required to obtain fracture is the Erichsen value for the metal. Erichsen standard values for trade qualities of soft metal sheets are furnished by the manufacturer of the machine corresponding to various sheet thicknesses. (See Proc. A. S. T. M. 17, part 2, p. 200, 1917.)

Alloy steels are commonly used in the heat treated condition, as strength increases are not commensurate with increases in production costs for annealed alloy steels. Corresponding strength values are accordingly shown for annealed alloy steels and for such steels after having been given certain recommended heat treatments of the Society of Automotive Engineers. The heat treatments followed in obtaining the properties shown are outlined on the pages immediately following the tables on steel. It will be noted that considerable latitude is allowed in the indicated drawing temperatures and corresponding wide variations in physical properties may be obtained with each heat treatment. The properties vary also with the size of the specimens heat treated. The drawing temperature is shown with the letter denoting the heat treatment, wherever the information is available.

MECHANICAL PROPERTIES

Iron and Iron Alloys

Metal. Grade.	Yield point. Tension kg/mm²	Ultimate strength. Tension kg/mm²	Yield point. Tension lb/in²	Ultimate strength. Tension lb/in²	Elong. in 50.8 mm (2 in.). Per cent.	Reduct. in area. Per cent.	Hardness. Brinell at 3000 kg	Hardness. Scleroscope.
Iron:								
Electrolytic* (remelt): as forged...	34.0	38.5	48,500	55,000	33.0	83.0	95 †	18
annealed 900° C	12.5	27.0	18,000	38,000	52.0	87.0	75 †	—
Gray cast‡(19 mm diam. bars)	indet.	17.5	indet.	25,000	negligible		100	24
	—	26.5	—	38,000	—	—	150	40
Malleable cast, American (after	14.0	24.5	20,000	35,000	15.0	15.0	—	—
Hatfield)	31.5	40.0	45,000	57,000	4.5	4.5	—	—
European (after Am. Malleable	19.0	29.5	27,000	42,000	6.0	6.0	—	—
Castings Ass.)	28.0	45.5	40,000	65,000	2.0	2.0	—	—
(see p. 653)								
Commercial wrought	19.5	34.0	28,000	48,000	40.0	45.0	—	25
	22.5	37.0	32,000	53,000	30.0	35.0	—	30
Silicon alloys‖ **Si 0.01:** as forged...	29.5	31.5	41,800	45,200	35.0	78.0	—	—
(Melted in vacuo) ann. 970° C	11.0	24.5	16,000	34,900	53.0	81.5	—	—
(Note: C max. 0.01 per cent)								
Si 1.71: as forged............	48.0	53.5	68,100	76,300	37.0	82.0	—	—
annealed 970° C........	25.0	38.0	35,800	54,200	50.0	90.6	—	—
Si 4.40: as forged............	66.0	74.0	94,000	105,000	6.0	7.5	—	—
annealed 970° C	51.0	64.5	72,900	91,600	24.0	25.1	—	—
Aluminum alloys¶ **Al 0.00:** as forged	35.5	38.5	50,700	54,700	26.0	84.3	—	—
(Melted in vacuo) ann. 1000° C	12.5	24.5	17,600	34,900	60.0	93.5	—	—
(Note: C max. 0.01 per cent)								
Al 3.08: as forged...........	48.0	54.5	68,200	77,500	21.0	76.4	—	—
annealed 1000° C	22.5	37.5	31,800	53,400	51.0	85.3	—	—
Al 6.24: as forged...........	54.5	60.5	77,700	86,000	28.0	74.7	—	—
annealed 1000° C	37.5	49.0	53,400	69,800	27.0	55.5	—	—

Composition, approximate:
Electrolytic, C 0.0125 per cent; other impurities less than 0.05 per cent.
Cast, gray: Graphitic, C 3.0, Si 1.3 to 2.0, Mn 0.6 to 0.9, S max. 0.1, P max. 1.2.
A. S. T. M. Spec. A48 to 18 allows S max. 0.10, except S max. 0.12 for heavy castings.
Malleable: American "Black Heart," C 2.8 to 3.5, Si 0.6 to 0.8, Mn max. 0.4, S max. 0.07, P max. 0.2.
European "Steely Fracture," C 2.8 to 3.5, Si 0.6 to 0.8, Mn 0.15, S max. 0.35, P max. 0.2.

Compressive Strengths [Specimens tested: 25.4 mm (1 in.) diam. cylinders 76.2 mm (3 in.) long].
Electrolytic iron 56.5 kg/mm² or 80,000 lb/in².
Gray and malleable cast iron 56.5 to 84.5 kg/mm² or 80,000 to 120,000 lb/in².
Wrought iron, approximately equal to tensile yield point (slightly above P-limit).

Density:
Electrolytic iron............. 7.8 g/cm³ or 487 lb/ft³ Malleable iron............... see page 653
Cast iron................... 7.2 g/cm³ or 449 lb/ft³ Wrought iron............... 7.85 g/cm³ or 490 lb/ft³

Ductility: — Normal Erichsen values for good trade quality sheets, 0.4 mm (0.0156 in.)

Thickness, soft annealed.	Depth. mm	Depth. in.
Sheet metal hoop iron, polished	9.5	0.374
Charcoal iron tinned sheet	7.5	0.295
Second quality tinned sheet	6.7	0.264

Modulus of elasticity in tension and compression:
Electrolytic iron.... 17,500 kg/mm² or 25,000,000 lb/in² Malleable iron... see page 653
Cast iron.......... 10,500 kg/mm² or 15,000,000 lb/in² Wrought iron.... 17,500 kg/mm² or 25,000,000 lb/in²

Modulus of elasticity in shear:
Electrolytic iron.......7030 kg/mm² or 10,000,000 lb/in² Cast iron .... 8450 kg/mm² or 12,000,000 lb/in²
Wrought iron..................... 7030 kg/mm² or 10,000,000 lb/in²

Scleroscope hardness values shown are as determined with the Shore Universal hammer.

Strength in Shear:
Electrolytic (remelt)
P-limit............... 8.4 kg/mm² or 12,000 lb/in²
Ultimate strength..... 21.1 kg/mm² or 30,000 lb/in²
Commercial wrought
P-limit........... 21.1 kg/mm² or 30,000 lb/in²
Ultimate strength.. 35.0 kg/mm² or 50,000 lb/in²

Transverse strength, from flexure formula:
Gray cast iron
Modulus of rupture, 33.0 kg/mm² or 47,000 lb/in²
"Arbitration Bar," 31.8 mm (1¼ in.) diameter, or 304.8 mm (12 in.) span; minimum central load at rupture 1130 to 1500 kg (2500 to 3300 lb.); minimum central deflection at rupture 2.5 mm (0.1 in.), (A. S. T. M. Spec. A 48-18).

* Properties of Swedish iron (impurities less than 1 per cent) approximate those of electrolytic iron.
† These two values of B. h. n. only are as determined at 500 kg pressure.
‡ U. S. Navy specifies minimum tensile strength of 14.1 kg/mm² or 20,000 lb/in².
‖ From T. D. Yensen, University of Illinois, Engr. Exp. Station, Bulletin No. 83, 1915 (shows Si 4.40 as alloy of maximum strength).
¶ From T. D. Yensen, University of Illinois, Engr. Exp. Station, Bulletin No. 95, 1917.

MECHANICAL PROPERTIES

TABLE 49. — Carbon Steels — Commercial Experimental Values

S. A. E. (Soc. of Automotive Eng., U. S. A.) classification scheme used as basis for steel groupings. First two digits S. A. E. Spec. No. show steel group number, and last two (or three in case of five figures) show carbon content in hundredths of one per cent.

The first lines of properties for each steel show values for the rolled or forged metal in the annealed or normalized condition. Comparative heat-treated values show properties after receiving modified S. A. E. heat treatment as shown below (Table 50). The P-limit and ductility of cast steel average slightly lower and the ultimate strength 10 to 15 per cent higher than the values shown for the same composition steel in the annealed condition. The properties of rolled steel (raw) are approximately equal to those shown for the annealed condition, which represents the normalized condition of the metal rather than the soft annealed state.

The data for heat-treated strengths are average values for specimens for heat treatment ranging in size from ½ to 1½ in. diameter. The final drawing or quenching temperature for the properties shown is indicated in degrees C with the heat treatment letter, wherever the information is available. In general, specimens were drawn near the lower limit of the indicated temperature range.

Metal.	S. A. E. spec. no.	Nominal contents per cent.	S.A.E. heat treatment.	P-limit. Tension kg/mm²	Ultimate strength. Tension kg/mm²	P-limit. Tension lb/in²	Ultimate strength. Tension lb/in²	Elong. in 50.8 mm (2 in.). Per cent	Reduct. in area. Per cent	Hardness Brinell (@ 3000 kg.)	Hardness Scleroscope.
Steel, carbon	1010	See Spec. No.	Ann.	24.0	32.0	34,500	46,000	37.0	72.0	—	18
	1010		A	27.0	42.0	39,000	60,000	30.0	62.0	120	24
	1020	(Mn 0.45)	Ann.	28.0	38.0	39,500	54,400	32.0	68.0	100	17
	1020		H 230° C	35.0	56.0	49,500	79,500	20.0	59.0	176	35
	1045	(Mn 0.65)	Ann.	40.0	50.0	57,500	71,300	23.0	54.0	168	27
	1045		H 260° C	62.0	86.0	88,000	123,000	13.5	36.0	290	45
	1095	(Mn 0.35)	Ann.	42.0	56.0	59,500	79,000	21.0	51.0	187	29
	1095		F 510° C	84.0	123.0	120,000	175,000	6.0	18.0	551	75

Specification values: **Steel, castings,** Ann. A.S.T.M. A27-16, Class B;* P max. 0.06; S max. 0.05.

Grade.	Yield point.	Ultimate tensile strength. kg/mm²	Ultimate tensile strength. lb/in²	Per cent elong. 50.8 mm or 2 in.	Per cent reduct. area.
Hard	0.45 ultimate	56.2	80,000	15	20
Medium	0.45 "	49.2	70,000	18	25
Soft	0.45 "	42.2	60,000	22	30

Structural Steel: Rolled: S max. 0.05; P-Bess. max. 0.10; -O-H. max. 0.06.

Tension: Yield Point min. = 0.5 ultimate; ultimate = 38.7 to 45.7 kg/mm² or 55,000 to 65,000 lb/in² with 22% min. elongation in 50.8 mm (2 in.).

* Average carbon contents: steel castings, C 0.30 to 0.40; structural steel, C 0.15 to 0.30 (mild carbon or medium hard steel).

TABLE 50. — Explanation of Heat Treatment Letters used in Table of Steel Data

Motor Transport Corps Modified S. A. E. Heat Treatments for Steels. (S. A. E. Handbook, Vol. 1, pp. 9d and 9e, 1915, q. v. for alternative treatments.)

Heat Treatment A. — After forging or machining (1) carbonize at a temperature between 870 and 930° C (1600 and 1700° F); (2) cool slowly; (3) reheat to 760 to 820 C (1400 to 1500° F.) and quench in oil.

Heat Treatment D. — After forging or machining: (1) heat to 820 to 840° C (1500 to 1550° F.); (2) quench; (3) reheat to 790 to 820° C (1450 to 1500° F.); (4) quench; (5) reheat to 320 to 650° C (600 to 1200° F.) and cool slowly.

Heat Treatment F. — After shaping or coiling: (1) heat to 775 to 800° C (1425 to 1475° F.); (2) quench; (3) reheat to 200 to 480° C (400 to 900° F.) in accordance with degree of temper required and cool slowly.

Heat Treatment H. — After forging or machining: (1) heat to 820 to 840° C (1500 to 1550° F.); (2) quench; (3) reheat to 230 to 650° C (450 to 1200° F.) and cool slowly.

Heat Treatment L. — After forging or machining: (1) carbonize at a temperature between 870 and 950° C (1600 and 1750° F.), preferably between 900 and 930° C (1650 and 1700 F.); (2) cool slowly in carbonizing material; (3) reheat to 790 to 820° C (1450 to 1500° F.); (4) quench; (5) reheat to 700 to 760° C (1300 to 1400° F.); (6) quench; (7) reheat to 120 to 260° C (250 to 500 F.) and cool slowly.

Heat Treatment M. — After forging or machining (1) heat to 790 to 820° C (1450 to 1500° F.); (2) quench; (3) reheat to between 260 and 680° C (500 and 1250° F.) and cool slowly.

Heat Treatment P. — After forging or machining: (1) heat to 790 to 820° C (1450 to 1500° F.); (2) quench; (3) reheat to 750 to 770° C (1375 to 1425° F.); (4) quench; (5) reheat to 260 to 650° C (500 to 1200° F.) and cool slowly.

Heat Treatment T. — After forging or machining: (1) heat to 900 to 950° C (1650 to 1750° F.); (2) quench; (3) reheat to 260 to 700° C (500 to 1300° F.) and cool slowly.

Heat Treatment U. — After forging: (1) heat to 830 to 870° C (1525 to 1600° F.), hold half an hour; (2) cool slowly; (3) reheat to 900 to 930° C (1650 to 1700° F.); (4) quench; (5) reheat to 180 to 290° C (350 to 550° F.) and cool slowly.

Heat Treatment V. — After forging or machining. (1) heat to 900 to 950° C (1650 to 1750° F.); (2) quench; (3) reheat to between 200 and 650° C (400 and 1200° F.) and cool slowly.

EDITOR'S NOTE: Oil quenching is recommended wherever the instructions specify "quench," inasmuch as the data in the table are taken from tests of automobile parts which must resist considerable vibration and which are usually small in section. The quenching medium must always be carefully considered.

Table 51
MECHANICAL PROPERTIES
Alloy Steels — Commercial Experimental Values

Metal.	S. A. E. spec. no.	Nominal contents, per cent.	S. A. E. heat treatment.	P-limit. Tension kg/mm²	Ultimate strength. Tension kg/mm²	P-limit. Tension lb/in²	Ultimate strength. Tension lb/in²	Elong. in 50.8 mm (2 in.). Per cent.	Reduct. in area. Per cent.	Hardness. Brinell (@ 3000 kg.)	Hardness. Scleroscope.
Steel, nickel . .	2315	—	Ann.	30.0	38.0	42,500	54,000	32.0	60.0	138	—
	2315	—	H	53.0	76.0	75,000	107,500	18.0	55.0	321	43
	2335	Ni 3.50	Ann.	39.0	48.0	55,000	68,000	24.0	53.0	165	—
	2335		H	106.0	131.0	151,000	186,000	15.0	51.0	465	62
	2345	(Mn 0.65)	Ann.	44.0	55.0	62,500	78,000	21.0	48.0	172	—
	2345		H	136.0	149.0	193,000	212,000	12.0	45.0	570	76
	Invar	Ni 36.0 C 0.40	Ann.	50.0	77.5	71,000	110,000	30.0	50.0	—	—
nickel chrome . . .	3120	Ni 1.25	Ann.	34.0	44.0	49,000	62,000	23.0	53.0	155	22
	3120	Cr 0.60	H 450° C	60.0	82.0	85,000	116,000	23.0	48.0	270	36
	3135		Ann.	40.0	50.0	57,000	71,300	20.0	46.0	182	30
	3135	(Mn 0.65)	H or D	88.0	121.0	125,000	172,000	18.0	43.0	330	44
	3220		Ann.	39.0	49.0	55,000	69,000	21.0	50.0	170	—
	3220	Ni 1.75	H or D	77.0	106.0	110,000	151,000	23.0	48.0	375	50
	3250	Cr 1.10	Ann.	44.0	55.0	62,000	78,000	19.0	42.0	180	—
	3250	(Mn 0.45)	M	134.0	183.0	190,000	260,000	16.0	32.0	480	64
	3320		Ann.	32.0	42.0	46,000	59,500	21.0	50.0	—	—
	3320	Ni 3.50	L	77.0	105.0	110,000	150,000	23.0	48.0	375	50
	3340	Cr 1.50	Ann.	39.0	52.0	56,000	74,000	18.0	45.0	—	—
	3340	(Mn 0.45)	P	120.0	163.0	170,000	232,000	18.0	42.0	479	64
chromium .	51120	Cr 1.00	Ann.	44.0	58.0	62,000	82,000	16.0	31.0	—	—
	51120	(Mn 0.35)	M or P	144.0	193.0	205,000	275,000	7.0	26.0	500	66
	52120	Cr 1.20	Ann.	44.0	58.0	62,000	82,000	13.0	24.0	—	—
	52120	(Mn 0.35)	M or P	141.0	178.0	200,000	253,000	7.0	25.0	524	70
chrome vanadium	6130	(Mn 0.65)	Ann.	43.0	59.0	61,500	84,500	23.0	51.0	152	—
	6130	Cr 0.95 V 0.18	T	84.0	115.0	120,000	163,000	16.0	43.0	432	59
	6195	(Mn 0.35)	Ann.	48.0	63.0	68,200	90,000	16.0	38.0	—	—
	6195		U	176.0	232.0	250,000	330,000	8.0	24.0	562	75
silico-manganese	9250	Si 1.95	Ann.	42.0	54.0	60,000	77,000	16.0	28.0	—	—
	9250	Mn 0.70	V	91.0	122.0	130,000	174,000	14.0	24.0	441	59
	9×30	Si 0.85	Ann.	48.0	61.0	68,000	87,000	13.0	22.0	—	—
	9×30	Mn 1.75	V	113.0	148.0	160,000	211,000	12.0	21.0	470	63
tungsten . .	(C–73)	W 2.4	Ann.	34.0	59.0	48,100	84,200	20.5	31.5	—	—
	(C–70)	W 9.7	Ann.	63.0	89.0	90,000	126,000	14.0	22.1	—	—
	(C–47)	W 15.6	Quench 1065° Draw 205° C	158.5	175.0	225,000	248,000	6.0	43.0	520	64

General Note. — Table on steels after Motor Transport Corps, Metallurgical Branch of Engineering Division, Table No. 88.

Maximum allowable P 0.045 or less, maximum allowable S 0.05 or less.

Silicon contents were not determined by Motor Transport Corps in preparing table, except for silico-manganese steels.

Compressive strengths:
For all steels approx. equal to yield point in tension (slightly above P-limit).

Density:
Steel weighs about 7.85 g/cm³ or 490 lb/ft³

Ductility, Erichsen values:
0.75 mm (0.029 in.) thick, low carbon soft annealed sheet (B. S.), depth of indentation 12.0 mm or 0.472 in.
1.30 mm (0.050 in.) thick, low carbon soft annealed sheet (B. S.), depth of indentation 12.5 mm or 0.492 in.

Modulus of elasticity in tension and compression:
For all steels approx. 21,000 kg/mm² = 30,000,000 lb/in².

Modulus of elasticity in shear:
For all steels approx. 8400 kg/mm² = 12,000,000 lb/in².

Scleroscope hardness values shown are as determined with the Shore Universal hammer.

Strength in shear:
P-limit and ultimate strength each about 70 per cent corresponding tensile values.

MECHANICAL PROPERTIES

TABLE 52. — Steel Wire — Specification Values

(After I. A. S. B. Specification 3S12, Sept., 1917, for High-strength Steel Wire.)

S. A. E. Carbon Steel, No. 1050 or higher number specified (see Carbon steels above). Steel used to be manufactured by acid open-hearth process, to be rolled, drawn, and then uniformly coated with pure tin to solder readily.

American or B. and S. wire gage.	Diameter.		Req'd twists in 203.2 mm or 8 in.	Weight.		Req'd bends thru 90°	Spec. minimum tensile strength.			
	mm	in.		kg/100 m	lb/100 ft.		kg	lb.	kg/mm²	lb/in²
6	4.115	0.162	16	10.44	7.01	5	2040	4500	154	219,000
7	3.665	.144	19	8.28	5.56	6	1680	3700	161	229,000
8	3.264	.129	21	6.55	4.40	8	1360	3000	164	233,000
9	2.906	.114	23	5.21	3.50	9	1135	2500	172	244,000
10	2.588	.102	26	4.12	2.77	11	910	2000	172	244,000
11	2.305	.091	30	3.28	2.20	14	735	1620	179	254,000
12	2.053	.081	33	2.60	1.74	17	590	1300	177	252,000
13	1.828	.072	37	2.06	1.38	21	470	1040	179	255,000
14	1.628	.064	42	1.64	1.10	25	375	830	181	258,000
15	1.450	.057	47	1.30	0.87	29	300	660	182	259,000
16	1.291	.051	53	1.03	0.69	34	245	540	186	264,000
17	1.150	.045	60	0.81	0.55	42	195	425	188	267,000
18	1.024	.040	67	0.65	0.43	52	155	340	190	270,000
19	0.912	.036	75	0.51	0.34	70	125	280	193	275,000
20	0.812	.032	85	0.41	0.27	85	100	225	197	280,000
21	0.723	.028	96	0.32	0.22	105	80	175	200	284,000

NOTE. — Number of 90° bends specified above to be obtained by bending sample about 4.76 mm (0.188 in.) radius, alternately, in opposite directions.

(Above specification corresponds to U. S. Navy Department Specification 22W6, Nov. 1, 1916, for tinned, galvanized or bright aeroplane wire.)

TABLE 53.— Steel Wire — Experimental Values

(Data from tests at General Electric Company laboratories.) "Commercial Steel Music Wire (Hardened)."

Diameter.		Ultimate strength.	
mm	in.	kg/mm² tension	lb/in²
12.95	0.051	226.0	321,500
11.70	.046	249.0	354,000
9.15	.036	253.0	360,000
7.60	.030	260.0	370,000
6.35	.025	262.0	372,500
4.55	.018	265.5	378,000
2.55*	.010	386.5	550,000
1.65*	.0065	527.0	750,000
4.55†	.018	49.2	70,000

* For 4.55 mm wire drawn cold to indicated sizes. † For 4.55 mm (0.018 in.) wire annealed in H_2 at 850° C.

TABLE 54.— Semi-steel

Test results at Bureau of Standards on 155-mm shell, Jan. 1919.
Microstructure — matrix resembling pearlitic steel, embedded in which are flakes of graphite.
Composition-Comb. C 0.60 to 0.76, Mn 0.88, P 0.42 to 0.43, S 0.077 to 0.088, Si 1.22 to 1.23, graphitic C 2.84 to 2.94.

Metal.	P-limit.	Ultimate strength.	P-limit.	Ultimate strength.	P-limit.	Ultimate strength.	P-limit.	Ultimate strength.	Hardness.	
	Tension kg/mm²		Tension lb/in²		Compression kg/mm²		Compression lb/in²		Brinell @3000 kg	Scleroscope.
Semi-steel:										
Graph. C 2.85, Comb. C 0.76	7.9	19.8	11,200	28,200	24.3	72.6	34,500	103,000	176	—
Graph. C 2.92, Comb. C 0.60	4.2	14.9	6,000	21,200	18.3	61.4	26,000	87,300	170	—

Tension specimens 12.7 mm (0.5 in.) diameter, 50.8 mm (2 in.) gage length; elongation and reduction of area negligible.
Compression specimens 20.3 mm (0.8 in.) diameter, 61.0 mm (2.4 in.) long; failure occurring in shear.
Tension set readings with extensometer showed elastic limit of 2.1 kg/mm² or 3000 lb/in².
Modulus of elasticity in tension — 9560 kg/mm² or 13,600,000 lb/in².

TABLE 55. — Steel-wire Rope — Specification Values

Cast steel wire to be of hard crucible steel with minimum tensile strength of 155 kg/mm² or 220,000 lb/in² and minimum elongation of 2 per cent in 254 mm (10 in.).

Plow steel wire to be of hard crucible steel with minimum tensile strength of 183 kg/mm² or 260,000 lb/in² and minimum elongation of 2 per cent in 254 mm (10 in.).

Annealed steel wire to be of crucible cast steel, annealed, with minimum tensile strength of 77 kg/mm² or 110,000 lb/in² and minimum elongation of 7 per cent in 254 mm (10 in.).

Type A: 6 strands with hemp core and 19 wires to a strand (= 6 × 19), or 6 strands with hemp core and 18 wires to a strand with jute, cotton or hemp center.

Type B: 6 strands with hemp core, and 12 wires to a strand with hemp center.

Type C: 6 strands with hemp core, and 14 wires to a strand with hemp or jute center.

Type AA: 6 strands with hemp core, and 37 wires to a strand (= 6 × 37) or 6 strands with hemp core and 36 wires to a strand with jute, cotton or hemp center.

Description.	Diameter.		Approx. weight.		Minimum strength.	
	mm	in.	kg/m	lb/ft	kg	lb.
Galv. cast steel, Type A......	9.5	$\frac{3}{8}$	0.31	0.21	3,965	8,740
“ “ “ “ “	12.7	$\frac{1}{2}$	0.55	0.37	6,910	15,230
“ “ “ “ “	25.4	1	2.23	1.50	27,650	60,960
“ “ “ “ “	38.1	$1\frac{1}{2}$	5.06	3.40	63,485	139,960
Galv. cast steel, Type AA.....	9.5	$\frac{3}{8}$	0.35	0.22	3,840	8,460
“ “ “ “ “	12.7	$\frac{1}{2}$	0.58	0.39	7,410	16,330
“ “ “ “ “	25.4	1	2.23	1.50	27,650	60,960
“ “ “ “ “	38.1	$1\frac{1}{2}$	5.28	3.55	59,735	131,690
Galv. cast steel, Type B......	9.5	$\frac{3}{8}$	0.25	0.17	2,995	6,600
“ “ “ “ “	12.7	$\frac{1}{2}$	0.42	0.28	5,210	11,500
“ “ “ “ “	25.4	1	1.68	1.13	20,890	46,060
“ “ “ “ “	38.1	$1\frac{1}{2}$	3.94	2.65	47,965	105,740
Galv. cast steel, Type C......	25.4	1	1.59	1.07	18,825	41,500
“ “ “ “ “	41.3	$1\frac{5}{8}$	4.35	2.92	51,575	113,700
Galv. plow steel, Type A......	9.5	$\frac{3}{8}$	0.31	0.21	4,690	10,340
“ “ “ “ “	12.7	$\frac{1}{2}$	0.55	0.37	8,165	18,000
“ “ “ “ “	25.4	1	2.23	1.50	32,675	72,040
“ “ “ “ “	36.5	$1\frac{7}{16}$	4.66	3.13	69,140	152,430
Galv. plow steel, Type AA.....	9.5	$\frac{3}{8}$	0.33	0.22	4,540	10,000
“ “ “ “ “	12.7	$\frac{1}{2}$	0.58	0.39	8,750	19,300
“ “ “ “ “	25.4	1	2.35	1.58	32,250	71,100
“ “ “ “ “	41.3	$1\frac{5}{8}$	6.18	4.15	83,010	183,000

TABLE 56. — Steel-wire Rope — Experimental Values

(Wire rope purchased under Panama Canal Spec. 302 and tested by U. S. Bureau of Standards, Washington, D. C.)

Description and analysis.	Diameter.		Ultimate strength.		Ultimate strength (net area).	
	mm	in.	kg	lb.	kg/mm²	lb/in²
Plow Steel, 6 strands × 19 wires C 0.90, S 0.034, P 0.024, Mn 0.48, Si 0.172..............	50.8	2	137,900	304,000	129.5	184,200
Plow Steel, 6 strands × 25 wires C 0.77, S 0.036, P 0.027, Mn 0.46, Si 0.152..............	69.9	$2\frac{3}{4}$	314,800	694,000	151.2	214,900
Plow Steel, 6 × 37 plus 6 × 19 C 0.58, S 0.032, P 0.033, Mn 0.41, Si 0.160..............	82.6	$3\frac{1}{4}$	392,800	866,000	132.2	187,900
Monitor Plow Steel, 6 × 61 plus 6 × 19, C 0.82, S 0.025, P 0.019, Mn 0.23, Si 0.169...........	82.6	$3\frac{1}{4}$	425,000	937,000	142.5	202,400

Recommended allowable load for wire rope running over sheave is one fifth of specified min. strength.

TABLE 57. — Plow-Steel Hoisting Rope (Bright)

(After Panama Canal Specification No. 302, 1912.)

Wire rope to be of best plow steel grade, and to be composed of 6 strands, 19 wires to the strand, with hemp center. Wires entering into construction of rope to have an elongation in 203.2 mm or 8 in. of about $2\frac{1}{2}$ per cent.

Diameter.		Spec. minimum strength.		Diameter.		Spec. minimum strength.	
mm	in.	kg	lb.	mm	in.	kg	lb.
9.5	$\frac{3}{8}$	5,215	11,500	38.1	$1\frac{1}{2}$	74,390	164,000
12.7	$\frac{1}{2}$	9,070	20,000	50.8	2	127,000	280,000
19.0	$\frac{3}{4}$	20,860	46,000	63.5	$2\frac{1}{2}$	207,740	458,000
25.4	1	34,470	76,000	69.9	$2\frac{3}{4}$	249,350	550,000

MECHANICAL PROPERTIES

TABLE 58. — Aluminum

Metal, approx. composition, per cent.	Condition.	Density or weight. gm per cm³	Density or weight. lb. per ft³	P-limit. Tension, kg/mm²	Ultimate strength. Tension, kg/mm²	P-limit. Tension, lb/in²	Ultimate strength. Tension, lb/in²	Elong. in 50.8 mm (2 in.). Per cent.	Reduct. of area. Per cent.	Hardness. Brinell @ 500 kg	Hardness. Sclero-scope.
ALUMINUM: Av. Al 99.3 Imp., Fe and Si. .	Cast, sand at 700° C.	2.57	160.5	6.0 to 7.0	8.0 to 9.8	8,500 to 10,000	12,000 to 14,000	29 to 15	36 to 22	25 to 26	4 to 5
	Cast, sand and heat treated Ann. 500° C, air cooled.	—	—	—	8 9 to 9.6	—	12,600 to 13,600	28 to 18	30 to 22	25 to 27	4 to 5
	Cast, chill.	2.57	160.5	6.0	9.0	9,000	13,000	20.0	—	26	5
	Sheet, ann.	2.69	168.0	6.0	9.0	8,500	13,500	23.0	25.0	—	—
	Sheet, hard.	2.70	168.5	14.0	21.0	20,000	30,000	4.0	25.0	—	14
	Bars, hard.	2.70	168.5	15.0	23.0	22,000	33,000	—	35.0	—	—
	Wire, hard.	2.70	168.5	21.0	28.0	30,000	40,000	6.0	50.0	—	—

Compressive strength: cast, yield point 13.0 kg/mm² or 18,000 lb/in²; ultimate strength 47.0 kg/mm² or 67,000 lb/in².

Modulus of elasticity: cast, 6900 kg/mm² or 9,810,000 lb/in² at 17° C.

TABLE 59. — Aluminum Sheet

(*a*) *Grade A (Al min. 99.0) Experimental Erichsen and Scleroscope Hardness Values.*

[From tests on No. 18 B. & S. Gage sheet rolled from 6.3 mm (0.25 in.) slab. Iron Age v. 101, page 952].

Heat treatment annealed.	Thickness, mm	Indentation, mm	Scleroscope hardness.
None (as rolled).	1.08	6.83	14.0
@ 200° C, 2 hours	1.09	8.86	8.0
@ 300° C, 2 hours	1.07	10.17	4.5
@ 400° C, 2 hours	1.08	9.40	4.5
@ 200° C, 30 min.	1.07	7.97	11.8
@ 400° C, 30 min.	1.08	9.80	4.5

(*b*) *Specification Values.* — (1) Cast: U. S. Navy 49 Al, July 1, 1915; Al min. 94, Cu max. 6, Fe max. 0.5, Si max. 0.5, Mn max. 3.

Minimum tensile strength 12.5 kg/mm² or 18,000 lb/in² with minimum elongation of 8 per cent in 50.8 mm (2 in.).

(2) Sheet, Grade A: A. S. T. M. 25 to 18T; Al min. 99.0; minimum strengths and elongations.

Gage, sheet thicknesses. (B. & S.)	Gage, sheet thicknesses. mm	Gage, sheet thicknesses. in.	Temper, No. hardness.	Tensile strength. kg/mm²	Tensile strength. lb/in²	Elong. in 50.8 mm or 2 in. per cent.	
12 to 16 incl.	2.052 to 1.293	0.0808 to .0509	1 Soft, Ann.	8.8	12,500	30	Sheets of temper No. 1 to withstand being bent double in any direction and hammered flat; temper No. 2 to bend 180° about radius equal to thickness without cracking.
			2 Half-hard	12.5	18,000	7	
			3 Hard	15.5	22,000	4	
17 to 22 incl.	1.152 to 0.643	.0453 to .0253	1 Soft, Ann.	8.8	12,500	20	
			2 Half-hard	12.5	18,000	5	
			3 Hard	17.5	25,000	2	
23 to 26 incl.	0.574 to 0.404	.0226 to .0159	1 Soft, Ann.	8.8	12,500	10	
			2 Half-hard	12.5	18,000	5	
			3 Hard	21.0	30,000	2	

NOTE. — Tension test specimen to be taken parallel to the direction of cold rolling of the sheet.

Table 60
MECHANICAL PROPERTIES
Aluminum Alloys

Alloy, approx. composition per cent.	Condition, per cent reduction.	Density or weight, gm/cm³	Density or weight, lb/ft³	P-limit. Tension, kg/mm²	Ultimate strength. Tension, kg/mm²	P-limit. Tension, lb/in²	Ultimate strength. Tension, lb/in²	Elong. in 50.8 mm (2 in.). Per cent.	Reduct. of area. Per cent.	Hardness. Brinell @ 500 kg	Hardness. Sclero-scope.
Aluminum — Copper	Cast, chill	—	—	5.3	10.5	7,500	15,000	24.0	34.0	—	—
Al 98 Cu 1 Imp. max. 1	Rolled, 70%	—	—	19.0	21.0	27,000	30,000	4.0	—	—	—
Al 96 Cu 3 Imp. max. 1	Cast, chill	—	—	8.1	13.7	11,500	19,500	12.0	21.0	—	—
	Rolled, 70%	—	—	25.0	28.8	35,000	41,000	5.5	—	—	—
Al 94 Cu 5 Imp. max. 1	Cast, chill	—	—	10.0	15.0	14,500	21,500	7.0	14.0	—	—
	Rolled, 70%	—	—	23.0	27.0	33,000	38,000	6.0	—	—	—
Al 92 Cu 8: Alloy No. 12	Cast, sand	2.88	180	7.7 to	10.5 to	11,000 to	15,000 to	4.0 to	3.5 to	50 to	13 to
		—	—	10.5	16.2	15,000	23,000	None	None	65	18
Al 90–92 Cu 7–8.5 Imp. max. 1.7	Cast*	2.9	181	—	12.7	—	18,000	1.0	—	—	—
Copper, Magnesium	Cast at 700° C.	—	—	3.2 to	9.6 to	4,500 to	13,600 to	2.0 to	0.5 to	74 to	17 to
Al 9.52 Cu 4.2 Mg 0.6				4.6	13.3	6,500	18,900	0	0	74	18
	Ann. 500° C.	—	—	4.6	17.3	6,500	24,900	3.0	1.0	80	21
Duralumin or 17S Alloy Al 94 Cu 4 Mg 0.5	Ann.	2.8	174	25.0	42.0	35,100	59,500	21.1	29.5	—	—
	Rolled 70%	—	—	53.0	56.0	75,400	79,600	4.0	13.2	—	—
	Rolled heat tr'd †	—	—	23.4	39.0	33,400	55,300	25.5	26.0	—	—
Copper, Manganese	Cast, chill	—	—	10.0	14.0	14,300	20,300	5.0	—	—	—
Al 96 Cu 2 Mn 2	Rolled, 20 mm	—	—	19.0	27.0	27,100	38,200	16.0	28.0	—	—
Al 96 Cu 3 Mn 1	Cast, chill	—	—	11.3	19.0	16,200	27,000	14.0	—	—	—
Naval Gun Factory	Cast, sand	2.8	175	—	14.0	—	20,000	12.0	—	—	—
Al 97 Cu 1.5 Mn 1	Forged	—	—	14.0	19.0	19,500	27,800	12.0	47.0	—	—
Al 94 Cu max. 6 Mn max. 3	Minimum ‡	—	—	—	12.7	—	18,000	8.0	—	—	—
Copper, Nickel, Mg Mn	Cast at 700° C.	—	—	3.5 to	17.9 to	5,000 to	25,500 to	6.0 to	8.5 to	54 to	9 to
Al 93.5 Cu 3.5 Ni 1.5 Mg 1 Mn 0.5		—	—	9.8	23.2	14,000	33,000	1.5	1.0	86	25
Copper, Nickel Mn	Cast at 700° C.	—	—	—	14.5 to	—	20,600 to	6.0 to	11.0 to	50 to	9 to
Al 94.2 Cu 3 Ni 2 Mn 0.8					21.4		30,500	1.0	2.0	91	27
Magnesium:											
Magnalium Al 95 Mg 5	Cast, sand	2.5	156	5.6	15.5	8,000	22,000	7.0	8.5	—	—
Al 77–98, Mg 23–2	Cast, chill	2.4 to	150 to	—	29.5 to	—	42,000 to	—	—	—	—
		2.57	160		45.0		64,000				
Nickel Al 97 Ni 2	Cast, chill	—	—	4.0	11.0	5,800	14,900	21.0	36.0	—	—
	Drawn, cold	—	—	14.0	16.0	19,700	22,700	13.0	37.0	—	—
	Rolled, hot	—	—	8.0	13.0	11,900	18,200	28.0	52.0	—	—
Al 95 Ni 5	Cast, chill	—	—	6.0	15.0	9,000	21,700	9.0	11.0	—	—
	Drawn, cold	—	—	16.0	20.0	22,900	27,900	8.0	24.0	—	—
	Rolled, hot	—	—	9.0	16.0	13,500	22,300	22.0	36.0	—	—
Nickel Copper:											
Al 93.5 Ni 5.5 Cu 1	Cast, chill	—	—	7.0	17.0	10,700	24,800	6.0	8.0	—	—
Al 91.5 Ni 4.5 Cu 4	Cast, chill	—	—	7.0	18.0	9,900	25,200	4.0	5.0	—	—
Al 92 Ni 5.5 Cu 2	Drawn, cold	—	—	22.0	27.0	31,700	37,800	8.0	15.0	—	—
	Rolled, hot	—	—	13.0	22.0	18,200	31,500	16.0	24.0	—	—
Zinc, Copper:											
Al 88.6 Cu 3 Zn 8.4	Cast at 700° C.	—	—	4.7	18.5	6,700	26,300	8.0	7.5	50	10
	Ann. 500° C.	—	—	4.4	20.2	6,200	28,800	8.0	7.5	50	10
Al 81.1 Cu 3 Zn 15.9	Cast at 700° C.	3.1	193	9.8	24.7	14,000	35,100	2.0	2.0	74	15
	Ann. 500° C.	—	—	9.8	29.0	14,000	41,200	4.0	4.0	70	15

* Specification Values: Alloy "No. 12": A. S. T. M. B26–18T, tentative specified minimums for aluminum, copper.
† Quenched in water from 475° C after heating in a salt bath. Modulus of elasticity for Duralumin averages 7000 kg/mm² or 10,000,000 lb/in².
‡ Specification values: Aluminum castings; U. S. Navy 49 Al, July 1, 1915 (Impurities: Fe max. 0.5, Si max. 0.5)

MECHANICAL PROPERTIES

TABLE 61. — Copper

Metal and approx. composition. Per cent.	Condition.	Density or weight. gm/cm³	Density or weight. lb/ft³	P-limit. Tension, kg/mm²	Ultimate strength. Tension, kg/mm²	P-limit. Tension, lb/in²	Ultimate strength. Tension, lb/in²	Elong. in 50.8 mm (2 in.). Per cent.	Reduct. in area. Per cent.	Hardness. Brinell @ 500 kg	Hardness. Scleroscope.
Copper:											
99.9: electrolytic	Ann. 200° C......	8.89	555	6.0	27.0	8,500	38,000	50.0	50.0	40	7
Cu 99.6........	Cast............	8.85	552	7.0	18.0	10,000	25,000	20.0	60.0	80	8
Rolled.........	Hard, 40% reduct	8.89	555	14.0	35.0	20,000	50,000	5.0	8.0	94	—
	Ann. at 500° C...	8.90	556	indet.	25.0	indet.	35,000	50.0	60.0	42	6
Cu 99.6........	Drawn cold, 50% reduct.........	—	—	26.0	35.0	37,000	50,000	9.0	—	—	18
Cu 99.9 *.......	No Ann. (96% reduction).......	—	—	—	47.3	—	67,400	0.8	64.5	—	—
	Ann. 750° C after drawing cold...	—	—	—	21.9	—	31,200	24.5	76.0	—	—
Cu 99.9 †.......	Drawn hot (64% reduction).....	—	—	—	33.0	—	46,800	4.3	70.5	—	—

* Wire drawn cold from 3.18 mm (0.125 in.) to 0.64 mm (0.025 in.) Bull. Am. Inst. Min. Eng., Feb., 1919.
† Wire drawn at 150° C from 0.79 mm (0.031 in.) to 0.64 mm (0.025 in.) (Jeffries, *loc. cit.*).
Compression, cast copper, Ann. 15.9 mm (0.625 in.) diam. by 50.8 mm (2 in.) long cylinders.

Shortened 5 per cent at 22.0 kg/mm² or 31,300 lb/in² load.
" 10 " " " 29.0 kg/mm² " 41,200 lb/in² "
" 20 " " " 39.0 kg/mm² " 55,400 lb/in² "

Shearing strength, cast copper 21.0 kg/mm² or 30,000 lb/in²

Modulus of elasticity, electrolytic 12,200 kg/mm² or 17,400,000 lb/in²
" " " cast 7,700 kg/mm² or 11,000,000 lb/in²
" " " drawn, hard 12,400 kg/mm² or 17,600,000 lb/in²

TABLE 62. — Rolled Copper — Specification Values

Specification values: U. S. Navy Dept., 47C2, minimums for rolled copper, — Cu min. 99.5

Description, temper and thickness.	Tensile strength. kg/mm²	Tensile strength. lb/in²	Elong. in 50.8 or 2 in. — per cent.
Rods, bars, and shapes:			
Soft....................................	21.0	30,000	25
Hard: to 9.5 mm (⅜ in.) incl...............	35.0	50,000	10
Hard: 9.5 mm to 25.4 mm (1 in.)..........	31.5	45,000	12
Hard: 25.4 mm to 50.8 mm (2 in.)..........	28.0	40,000	15
Hard: over 50.8 mm (2 in.)................	24.5	35,000	20
Sheets and plates:			
Soft....................................	21.0 to 28.0	30,000 to 40,000	25 to 25
Hard....................................	24.5	35,000	18

TABLE 63. — Copper Wire — Specification Values

Specific Gravity 8.89 at 20° C (68° F).

Copper wire: Hard Drawn (and **Hard-rolled flat copper** of thicknesses corresponding to diameters of wire) Specification values. (A. S. T. M. B1-15, and U. S. Navy Dept., 22W3, Mar. 1, 1915.)

Diameter. mm	Diameter. in.	Minimum tensile strength. kg/mm²	Minimum tensile strength. lb/in²	Maximum elongation, per cent in 254 mm (10 in.).
11.68	.460	34.5	49,000	2.75
10.41	.410	35.9	51,000	3.25
9.27	.365	37.1	52,800	2.80
8.25	.325	38.3	54,500	2.40
7.34	.289	39.4	56,100	2.17
6.55	.258	40.5	57,600	1.98
5.82	.229	41.5	59,000	1.79
				in 1524 mm (60 in.)
5.18	.204	42.2	60,100	1.24
4.62	.182	43.0	61,200	1.18
4.12	.162	43.7	62,100	1.14
3.66	.144	44.3	63,000	1.09
3.25	.128	44.8	63,700	1.06
2.90	.114	45.2	64,300	1.02
2.59	.102	45.7	64,900	1.00
2.31	.091	46.0	65,400	0.97
2.06	.081	46.2	65,700	0.95
1.83	.072	46.3	65,900	0.92
1.63	.064	46.5	66,200	0.90
1.45	.057	46.7	66,400	0.89
1.30	.051	46.8	66,600	0.87
1.14	.045	47.0	66,800	0.86
1.02	.040	47.1	67,000	0.85

P-limit of hard-drawn copper wire must average 55 per cent of ultimate tensile strength for four largest sized wires in table, and 60 per cent of tensile strength for smaller sizes.

Table 64. — Copper Wire — Medium Hard-drawn

(A. S. T. M. B2–15) Minimum and Maximum Strengths.

Diameter.		Tensile strength.				Elongation, minimum per cent in 254 mm (10 in.).
		Minimum.		Maximum.		
mm	in	kg/mm²	lb/in²	kg/mm²	lb/in²	
11.70	0.460	29.5	42,000	34.5	49,000	3.75
6.55	.258	33.0	47,000	38.0	54,000	2.50
						in 1524 mm (60 in.)
4.12	.162	34.5	49,000	39.5	56,000	1.15
2.59	.102	35.5	50,330	40.5	57,330	1.04
1.02	.040	37.0	53,000	42.0	60,000	0.88

Representative values only from table in specifications are shown above.
P-limit of medium hard-drawn copper averages 50 per cent of ultimate strength.

TABLE 65.— Copper Wire — Soft or Annealed

(A. S. T. M. B3–15) Minimum Values.

Diameter.		Minimum tensile strength.		Elongation in 254 mm (10 in.), per cent.
mm	in.	kg/mm²	lb/in²	
11.70 to 7.37	0.460 to 0.290	25.5	36,000	35
7.34 to 2.62	0.289 to 0.103	26.0	37,000	30
2.59 to 0.53	0.102 to 0.021	27.0	38,500	25
0.51 to 0.08	0.020 to 0.003	28.0	40,000	20

NOTE. — Experimental results show tensile strength of concentric-lay copper cable to approximate 90 per cent of combined strengths of wires forming the cable.

TABLE 66.— Copper Plates

(A. S. T. M. B11–18) for Locomotive Fire Boxes. Specification Values.

Minimum requirements.	Tensile strength.		Elong. in 203.2 mm (8 in.), per cent.
	kg/mm²	lb/in²	
Copper, Arsenical, As 0.25–0.50 Impurities, max. 0.12........	22.0	31,000	35
Copper, Non-arsenical: Impurities, max. 0.12.......	21.0	30,000	30

NOTE. — Copper to be fire-refined or electrolytic, hot-rolled from suitable cakes.

TABLE 67.— Copper Alloys

The general system of nomenclature employed has been to denominate all simple copper-zinc alloys as **brasses,** copper-tin alloys as **bronzes,** and three or more metals alloys composed primarily of either of these two combinations as alloy brasses or bronzes, e.g., "Zinc bronze" for U. S. Government composition "G" Cu 88 per cent, Sn 10 per cent, Zn 2 per cent. Alloys of the third type noted above, together with other alloys composed mainly of copper, have been called **copper alloys,** with the alloying elements other than minor impurities listed as modifying copper in the order of their relative percentages.

In some instances, the scientific name used to denote an alloy is based upon the deoxidizer used in its preparation, which may appear either as a minor element of its composition or not at all, e.g., phosphor bronze.

Commercial names are shown below the scientific names. Care should be taken to specify the chemical composition of a commercial alloy, as the same name frequently applies to widely varying compositions.

Table 68

MECHANICAL PROPERTIES

Copper Alloys — Copper-Zinc or Brasses; Copper-Tin or Bronzes

Metal and approx. composition, per cent.	Condition.	Density or weight. gm/cm³	Density or weight. lb/ft³	P-limit. Tension, kg/mm²	Ultimate strength. Tension, kg/mm²	P-limit. Tension, lb/in²	Ultimate strength. Tension, lb/in²	Elong. in 50.8 mm (2 in.). Per cent.	Reduct. in area. Per cent.	Hardness. Brinell @ 500 kg	Hardness. Sclero-scope.
Brass:											
Cu 90 Zn 10†	Sand cast	—	—	—	20.0	—	29,000	22	—	—	—
	Cold rolled, hard	—	—	—	39.0	—	55,000 *	5 *	—	60	20
	Cold rolled, soft.	8.7	543	—	26.0	—	37,000 *	40 *	70	47	10
Cu 80, Zn 20 ‡	Sand cast	—	—	—	25.0	—	35,000	31	32	—	—
	Cold rolled, hard	—	—	—	53.0	—	75,000 *	5 *	—	75	28
	Cold rolled, soft.	8.6	537	—	29.0	—	42,000 *	50 *	85	46	12
Cu 70, Zn 30	Sand cast	8.4	524	—	28.0	—	40,000	35	—	37	—
Cu 66 Zn 34 Std. sheet	Cold rolled, hard	8.5	530	—	42.0	—	60,000	5 *	—	75§	26
	Cold rolled, soft.	8.4	524	—	34.0	—	48,000 *	50 *	85	45	12
Cu 60, Zn 40	Sand cast	—	—	15.5	32.2	21,800	45,800	15	22	—	—
Muntz metal	Cold rolled, hard	8.4	522	31.5	49.0	45,000	70,000	30	50	—	—
Bronze:											
Cu 97.7, Sn 2.3	Cast	—	—	6.0	19.5	8,500	28,000	20	—	—	—
	Rolled	—	—	7.6	34.0	10,800	48,000	55	75	—	—
Cu 90, Sn 10	Cast or gun bronze or bell metal	8.78	548	7.2	23.0	10,300	33,000	10	—	—	23
Cu 80, Sn 20	Cast	8.81	550	7.1	22.5	10,100	32,000	1.5	—	—	—
Cu 70, Sn 30	Cast	8.84	552	1.4	5.0	2,000	7,000	0.5	—	—	—

Compressive Strengths, **Brasses:**

Cu 90, Zn 10, cast 21.0 kg/mm² or 30,000 lb/in²
Cu 80, Zn 20, cast 27.4 kg/mm² or 39,000 lb/in²
Cu 70, Zn 30, cast 42.0 kg/mm² or 60,000 lb/in²
Cu 60, Zn 40, cast 52.5 kg/mm² or 75,000 lb/in²
Cu 50, Zn 50, cast 77.0 kg/mm² or 110,000 lb/in²

Modulus of elasticity, — cast brass, — average 9100 kg/mm² or 13,000,000 lb/in²
Erichsen values: Soft slab, 1.3 mm (0.05 in.) thick, no rolling, depth of impression 13.8 mm (0.55 in.).
Hard sheet, 1.3 mm, rolled 38% reduction, depth of impression 7.3 mm (0.29 in.).
Hard sheet, 0.5 mm, rolled 60% reduction, depth of impression 3.7 mm (0.15 in.).

Compressive Ultimate Strengths, Cast Bronzes:

Cu 97.7, Sn 2.3 to 24.0 kg/mm² or 34,000 lb/in²
Cu 90, Sn 10 to 39.0 kg/mm² or 56,000 lb/in²
Cu 80, Sn 20 to 83.0 kg/mm² or 118,000 lb/in²
Cu 70, Sn 30 to 105.0 kg/mm² or 150,000 lb/in²

Specification value, A. S. T. M., B 22–18 T, for specimen = cylinder 645 sq. mm (1 sq. in.) area, 25.4 mm (1 in.) long.
Cu 80, Sn 20: minimum compressive elastic limit = 17.0 kg/mm² or 24,000 lb/in²
Modulus of elasticity for bronzes varies from 7000 kg/mm² or 10,000,000 lb/in² to 10,000 kg/mm² or 15,500,000 lb/in²

* Values marked thus are S. A. E. Spec. values. (See S. A. E. Handbook, Vol. I, p. 13a, rev. December, 1913.)
† Red metal. ‡ Low brass or bell metal.
§ A. S. T. M. Spec. B19–18T requires B.h.n. of 51–65 kg/mm² @ 5000 kg pressure for 70: 30 annealed sheet brass.

Foot notes to Table 69, Page 121

* Tensilite, Cu 67, Zn 24, Al 4.4, Mn 3.8, P 0.01 compressive P-limit: 42.2 kg/mm² or 60,000 lb/in² and 1.33 per cent set for 70.3 kg/mm² or 100,000 lb/in² load.
† Compressive P-limit 20.0 to 28.2 kg/mm² or 28,500 to 40,000 lb/in²
‡ Compressive ultimate strength 54.5 kg/mm² or 77,500 lb/in²
§ Compressive P-limit 4.2 kg/mm² or 6000 lb/in² and 40 per cent set for 70.3 kg/mm² or 100,000 lb/in²
¶ Modulus of elasticity 9840 kg/mm² or 14,000,000 lb/in²
|| Values are for yield point. ** Minimum values for ingots.
†† Rolled manganese bronze (U. S. N.) Cu 57 to 60, Zn 40 to 37, Fe max. 2.0, Sn 0.5 to 1.5; 2.9 per cent increase for thickness 25.4 mm (1 in.) and under.
‡‡ Ni 9 per cent, B.h.n. = 130 as rolled; B.h.n. = 50 as annealed at 930° C.
U. S. Navy Dept. Spec. 46S 3a, June 1, 1917: German silver Cu 60 to 67, Zn 18 to 22, Ni min. 15, no mechanical requirements.
For list of 30 German silver alloys, see Braunt, "Metallic Alloys," p. 314, — "best" (Hiorns), "hard Sheffield," Cu 46, Zn 20, Ni 34.
§§ Platinoid Cu 60, Zn 24, Ni 14, W 1 to 2; high electric resistance alloy with mechanical properties as nickel brass
|||| Specification Values, Naval Brass Castings, U. S. Navy, 46B 10b, Dec. 1, 1917 for normal proportions Cu 62, Zn 37, Sn 1, min. tensile strength 17.5 kg/mm² or 25,000 lb/in² with 15 per cent elongation in 50.8 mm (2 in.).

Table 69
MECHANICAL PROPERTIES
Copper Alloys — Three (or more) Components

Alloy and approx. composition per cent.	Condition.	Density or weight. gm per cm³	Density or weight. lb. per ft³	P-limit. Tension, kg/mm²	Ultimate strength. Tension, kg/mm²	P-limit. Tension, lb/in²	Ultimate strength. Tension, lb/in²	Elong. in 50.8 mm (2 in.). Per cent.	Reduct. of area. Per cent.	Hardness. Brinell @ 500 kg	Hardness. Scleroscope.
Brass, Aluminum	Cast										
Cu 57, Zn 42, Al 1		—	—	—	40.0	—	57,000	50.0	—	—	—
Cu 55, Zn 41, Al 4		—	—	—	60.0	—	85,400	16.5	—	—	—
Cu 62.9, Zn 33.3, Al 3.8		—	—	—	56.2	—	80,000	—	—	—	—
Cu 70.5, Zn 26.4, Al 3.1		—	—	13.4	33.0	19,000	47,000	50.0	—	—	—
Alum., Manganese	Cast, tensilite*										
Cu 64, Zn 29, Al 3.1, Mn 2.5, Fe 1.2		—	—	21.1	68.8	30,000	98,000	16.0	17.0	130	—
Alum., Vanadium											
Cu 58.5, Zn 38.5, Al 1.5, V 0.03	Cold drawn	—	—	35.6	57.0	50,600	81,400	12.0	14.0	—	—
Iron:											
Cu 56, Zn 41.5, Fe 1.	Cast	—	—	—	50.7 to 59.2	—	72,000 to 84,000	35.0 to 22.0	35.0 to 25.0	109 to 119	—
Aich's Metal Cu 60, Zn 38.2, Fe 1.8	Cast	8.42	526	—	40.3	—	57,300	—	—	—	—
Delta Metal Cu 57, Zn 42, Fe 1	Cast, sand	—	—	—	31.7	—	45,000	10.0	—	—	—
	Rolled, hard	—	—	—	42.2	—	60,000	17.0	—	—	—
Cu 65, Zn 30, Fe 5	Rolled hard	—	—	—	45.5	—	65,000	—	—	—	—
Iron, Tin:											
Cu 56.5, Zn 40, Fe 1.5, Sn 1.0 †	Cast	—	—	23.2 to 26.0	49.2 to 52.8	33,000 to 37,000	70,000 to 75,000	35.0 to 20.0	35.0 to 22.0	104 to 119	—
Sterro metal: Cu 55, Zn 42.4 Fe 1.8, Sn 0.8	Cast	8.4	525	—	42.5	—	60,500	—	—	—	—
	Forged	—	—	—	53.6	—	76,200	—	—	—	—
	Hard drawn	—	—	—	58.5	—	83,100	—	—	—	—
Lead or Yellow brass	Cast	8.5	531	—	23.2 to 27.5	—	33,000 to 39,000	30.0 to 26.0	35.0 to 30.0	—	—
Cu 60 to 63.5, Zn 35 to 33.5, Pb 5 to 3	Sheet ann.	—	—	—	25.5	—	42,000	50.0	—	—	—
	Sheet hard	—	—	—	42.9	—	61,000	30.0	—	—	—
Lead, Tin or Red brass Cu 83, Zn 7, Pb 6, Sn 4	Cast ‡	8.6	535	11.0	21.0	16,000	30,000	17.0	19.0	—	7.0
Cu 78, Zn 9.5, Pb 10, Sn 2	Cast	8.87	554	8.4	18.6	12,000	26,500	22.0	24.9	—	—
Yellow brass: Cu 70, Zn 27, Pb 2, Sn 1	Cast §	8.4	524	7.4	20.7	10,500	29,500	25.0	28.5	53.0	—
Manganese or Manganese bronze											
Cu 58, Zn 39, Mn 0.05	Cast, sand ¶	8.3	520	21.1 to 24.6	49.2 to 52.7	30,000 to 35,000‖	70,000 to 75,000	30.0 to 22.0	32.0 to 25.0	109 to 119	18 to 19
(Sn, Fe, Al, Pb.)	Cast, chill	—	—	22.5 to 26.0‖	52.7 to 56.3	32,000 to 37,000‖	75,000 to 80,000	32.0 to 25.0	34.0 to 28.0	119 to 130	18 to 22
Cu 60, Zn 39 Mn, tr	Rolled	8.3	520	31.5	52.5	45,000	75,000	25.0	28.0	—	30
Specification values: U. S. Navy, 46 B 16a **		—	—	—	49.2	—	70,000	20.0	—	—	—
U. S. N., 46 B 15a	Rolled††	—	—	24.6	49.2	35,000	70,000	30.0	—	—	—
Manganese Vanadium:											
Cu 58.6, Zn 38.5, Al 1.5 Mn 0.5, V 0.03.	Cold drawn	—	—	35.6	57.0	50,600	81,400	12.0	14.0	—	—
Nickel: Nickel silver, Cu 60.4, Zn 31.8, Ni 7.7	Cast	8.5	530	10.8	25.3	15,400	36,000	40.5	42.0	46	—
German silver, Cu 61.6, Zn 17.2, Ni 21.1		8.7	544	13.2	28.8	18,800	40,900	28.5	25.1	80	—
Cu 60.6, Zn 11.8, Ni 27.3		8.8	547	16.7	37.6	23,700	53,500	32.0	31.4	67	—
Fine wire: Cu 58, Zn 24, Ni 18	Drawn hard	8.5	530	—	105.5	—	150,000	—	—	—	—
Nickel silver ‡‡											
Nickel Tungsten: §§											
Tin:											
Cu 61, Zn 38, Sn 1	Cast, sand	—	—	11.0	30.0	15,700	42,600	29.6	32.0	—	—
Naval brass, as above	Ann. after rolling	—	—	26.0	43.5	37,000	62,000	25.0	37.0	—	—
Tobin bronze: as below	Cast	8.3	518	17.6	42.2	25,000	60,000	—	—	—	—
Cu 58.2, Zn 39.5, Sn 2.3	Rolled	8.4	524	38.0	56.0	54,000	79,000	35.0	40.0	—	—
Cu 55, Zn 43, Sn 2.	Cast‖‖	—	—	—	48.4	—	68,900	48.0	70.0	—	—

For Footnotes see page 120.

MECHANICAL PROPERTIES

Copper Alloys — Three (or more) Components

Alloy and approx. composition per cent.	Condition.	Density or weight, gm per cm³	Density or weight, lb. per ft³	P-limit. Tension, kg/mm²	Ultimate strength. Tension, kg/mm²	P-limit. Tension, lb/in²	Ultimate strength. Tension, lb/in²	Elong. in 50.8 mm (2 in.). Per cent.	Reduct. of area. Per cent.	Hardness. Brinell @ 500 kg	Hardness. Scleroscope.
Brass, Tin — (continued):											
Rods:* 0 to 12.7 mm (½ in.)		—	—	19.0	42.2	27,000	60,000	35.0	To bend 120° cold about radius equal to diameter.		
12.7 to 25.4 mm (1 in.)		—	—	18.3	40.8	26,000	58,000	40.0			
over 25.4 mm (in.) diam.		—	—	17.6	38.0	25,000	54,000	40.0			
Shapes, all		—	—	15.7	39.4	22,400	56,000	30.0	"		
Plates to 12.7 mm (½ in.)		—	—	19.3	38.7	27,500	55,000	32.0	"		
over 12.7 mm (½ in.) thick		—	—	17.6	39.4	25,000	56,000	35.0	"		
Tubing (wall thickness) 0 to 3.2 mm (⅛ in.)		—	—	21.1	42.2	30,000	60,000	28.0	—	—	—
3.2 to 6.4 mm (¼ in.)		—	—	19.7	38.7	28,000	55,000	32.0	—	—	—
over 6.4 mm (¼ in.)		—	—	18.3	35.1	26,000	50,000	35.0	—	—	—
Vanadium:											
Victor bronze, V 0.03, Cu 58.6, Zn 38.5, Al 1.5, Fe 1.0	Cold drawn	—	—	56.5	64.5	80,000	92,000	11.5	29.0	—	—
U. S. Navy † 49 B 1b		—	—	15.8	38.7	22,500	55,000	25.0	—	—	—
Bronze, Aluminum	See Cu Al										
Lead:											
Cu 89, Sn 10, Pb 1	Cast ‡	—	—	—	15.5	—	22,000	—	—	—	—
Cu 88, Sn 10, Pb 2	Cast §	—	—	13.4 to 16.2	21.1 to 24.6	19,000 to 23,000	30,000 to 35,000	20.0 to 15.0	26.0 to 18.0	65 to 70	—
Cu 80, Sn 10, Pb 10	Cast, sand	8.8	549	10.9	22.1	15,500	31,400	13.5	12.0	63	—
	Cast, chill	—	—	12.8	24.7	18,200	35,200	4.5	3.5	85	—
Lead, Phosphor:											
Cu 80, Sn 10, Pb 10, P trace	Cast	9.1	570	11.0	21.0	16,000	30,000	6.0	3.5	65	12
Lead Zinc, Red brass:	Cast ǁ	—	—	13.8	18.8	19,600	26,800	11.0	11.5	—	8.0
Cu 81, Sn 7, Pb 9, Zn 3	Cast ¶	8.9	555	13.4 to 14.1	21.1 to 24.6	19,000 to 20,000	30,000 to 35,000	18.0 to 15.0	24.0 to 22.0	50 to 55	—
Cu 88, Sn 8, Pb 2, Zn 2	Cast	—	—	—	21.8 to 26.0	—	31,000 to 37,000	20.0 to 16.0	—	57 to 59	—
Lead, Zinc Phosphor:											
Cu 73.2, Sn 11.3, Pb 12.0, Zn 2.5, P 1	Cast **	—	—	10.5	21.4	15,000	30,400	4.0	3.3	—	11
Manganese:											
Cu 88, Sn 10, Mn 2	Cast	—	—	9.0	19.1	12,800	27,200	25.0	—	—	—
Nickel, Zinc:											
Cu 88, Sn 5, Ni 5, Zn 2 (1)	Cast††	—	—	9.2	28.6	13,100	40,700	32.0	28.0	—	—
Cu 89, Sn 4, Ni 4, Zn 3 (2)	Cast††	—	—	8.1	27.9	11,500	39,700	31.0	31.0	—	—
Phosphor:											
Cu 95, Sn 4.9, P 0.1	Rolled	8.6	535	28.0	46.0	40,000	65,000	30.0	—	—	37
Cu 89, Sn 10.5, P 0.5	Cast	—	—	11.2 to	21.8 to	16,000 to	31,000 to	6.0 to	—	72 to	—
Cu 80, Sn 20, P max. 1	Cast ‡‡			14.1	24.6	20,000	35,000	10.0		77	
Rods and bars §§ up to 12.7 mm (½ in.)		—	—	42.2ǁǁ	56.2	60,000	80,000	12.0	Required to bend cold through 120° about radius equal to thickness.		
(minimum) over 12.7 mm to 25.4 mm (1 in.)		—	—	28.1ǁǁ	42.2	40,000ǁǁ	60,000	20.0			
over 25.4 mm (1 in.)		—	—	21.1ǁǁ	38.7	30,000ǁǁ	55,000	25.0			
Sheets and plates §§ spring temper		—	—	—	63.2	—	90,000	—			
Medium temper		—	—	17.6ǁǁ	35.1	25,000ǁǁ	50,000	25.0	"		

Bronze, Phosphor: spring wire, hard-drawn or hard-rolled (U. S. Navy Spec. 22 W5, Dec. 1, 1915). Cu 94. Sn min. 4.5, Zn max 0.3, Fe max. 0.1, Pb max. 0.2, P 0.05 to 0.50; max. elong. in 203 mm (8 in.) = 4 per cent.

Diameter (group limits).	Min. tensile strength, kg/mm²	Min. tensile strength, lb/in²	Diameter (group limits), mm	Diameter (group limits), in.	Min. tensile strength, kg/mm²	Min. tensile strength, lb/in²
Up to 1.59 mm or 0.0625 in.	95.0	135,000	to 6.35	to 0.250	77.5	110,000
Over 1.59 mm to 3.17 mm (0.125 in.)	88.0	125,000	to 9.52	to 0.375	74.0	105,000

* Specification Values, Rolled Brass, Cu 62, Zn 37, Sn 1, min. properties after U. S. Navy Spec., 1918.
† Specification Values: Jan. 3, 1916, Vanadium Bronze Castings, Cu 61, Zn 38, Sn max. 1 (incl. V). Mimima.
‡ Compressive P-limit 15.5 kg/mm² or 22,000 lb/in²
§ Compressive P-limit 10.5 kg/mm² or 15,000 lb/in² and 28 per cent set for 70 kg/mm² or 100,000 lb/in²
ǁ Ultimate compressive strength, 54.2 kg/mm² or 77,100 lb/in² (Cu 76, Sn 7, Pb 13, Zn 4).
¶ Compressive P-limit 8.8 to 9.1 kg/mm² or 12,500 to 13,000 lb/in², and 34 to 35 per cent set for 70 kg/mm²
** Compression: ultimate strength 49.5 kg/mm² or 70,500 lb/in²
†† Modulus of Elasticity: (1) 12,200 kg/mm² or 17,300,000 lb/in²; (2) 10,500 kg/mm² or 14,900,000 lb/in²
‡‡ Compressive P-limit 17.6 to 28.1 kg/mm² or 25,000 to 40,000 lb/in² and 6 to 10 per cent set for 70 kg/mm² or 100,000 lb/in² load.
Specification Values: U. S. Navy 46 B 5c, Mar. 1, 1917, Cu 85 to 90, Sn 6 to 11, Zn max. 4: Cast, Grade 1. — Impurities max. 0.8; min. tensile strength 31.6 kg/mm² or 45,000 lb/in² with 20 per cent elong. in 50.8 mm (2 in.).
¶ Grade 2. — Impurities max. 1.6; min. tensile strength 21.1 kg/mm² or 30,000 lb/in² with 15 per cent elong. in 50.8 mm (2 in.).
§§ Specification Values: U. S. Navy 46B 14b, Mar. 1, 1916, Cu min. 94, Sn min. 3.5, P 0.50, rolled or drawn.
ǁǁ Minimum yield points specified: for P-limits assume 66 per cent of values shown.

TABLE 69 (*concluded*)

MECHANICAL PROPERTIES

Copper Alloys — Three (or more) Components

Alloy and approx. composition, per cent.	Condition.	Density or weight, gm per cm³	Density or weight, lb. per in³	P-limit. Tension, kg/mm²	Ultimate strength. Tension, kg/mm²	P-limit. Tension, lb/in²	Ultimate strength. Tension, lb/in²	Elong. in 50.8 mm (2 in.). Per cent.	Reduct. in area. Per cent.	Hardness. Brinell @ 500 kg	Hardness. Sclero-scope.
Bronze:											
Silicon	Cast	—	—	—	46.0	—	65,000	—	—	—	—
Cu 70, Zn 29.5, Si 0.5	Drawn, hard	—	—	—	74.0	—	105,000	—	—	—	—
Zinc * Comp. "G"	Cast	8.6	535	8.6	27.4	12,200	38,900	25.0	21.0	64	13
Admiralty gun metal. Comm'c'l range	Cast†	—	—	5.6 to 8.4	22.5 to 26.7	8,000 to 12,000	32,000 to 38,000	25.0 to 10.0	25.0 to 12.0	65 to 75	10 to 20
Spec. values	Cast (mins.)	—	—	—	21.1	—	30,000	14.0	—	—	—
Cu 88, Sn 8, Zn 4	Cast ‡	8.5	530	7.7	27.5	11,000	39,200	30.5	24.0	58	11
Cu 85, Sn 13, Zn 2	Cast	—	—	—	26.7	—	38,000	2.5	2.5	—	25
Zinc, Lead											
Cu 90, Sn 6.5, Zn 2, Pb 1.5	Cast §	—	—	8.4 to 11.2	23.9 to 28.1	12,000 to 16,000	34,000 to 40,000	33.0 to 25.0	34.0 to 26.0	50 to 60	—
Rods and bars ‖ up to 12.7 mm (½ in.)		—	—	28.1	56.2	40,000	80,000	30.0	Required to bend cold through 120° about radius equal to thickness.		
over 12.7 mm to 25.4 mm (1 in.)		—	—	26.4	52.7	37,500	75,000	30.0			
over 25.4 mm (1 in.)		—	—	24.6	50.7	35,000	72,000	30.0			
Shapes,‖ all thicknesses		—	—	26.4	52.7	37,500	75,000	30.0			
Sheets and plates,‖ o to 12.7 mm (½ in.)		—	—	27.4	54.8	39,000¶	78,000	30.0	"		
over 12.7 mm (½ in.)		—	—	26.4	52.7	37,500	75,000	30.0	"		
Aluminum Tin:											
Cu 88.5, Al 10.4, Sn 1.2	Cast, chill	—	—	26.0	48.0	36,700	68,000	4.5	5.5	189	32
Aluminum Titanium:											
Cu 90, Al 10	Cast **	—	—	13.9	52.0	19,800	74,000	19.5	23.7	100	25
	Quench, 800° C.	—	—	29.0	74.0	40,500	105,200	1.0	0.8	262	—
Cu 89, Al 10, Fe 1	Cast ††	7.58	473	14.1 to 17.6	45.7 to 56.2	20,000 to 25,000	65,000 to 80,000	30.0 to 20.0	30.0 to 20.0	93 to 100	25 to 26
Lead:											
Cu 71.9, Pb 27.5, Sn 0.5	Cast	—	—	—	4.2 to 4.6	—	6,000 to 6,600	3.0 to 3.2	4.2 to 6.7	—	—
Nickel, Aluminum:											
Cu 82.1, Ni 14.6, Al 2.5, Zn 0.7 ‡‡	Forged	—	—	44.5	90.0	63,300	128,000	10.0	12.0	—	—
Cu 85, Sn 5, Zn 5, Pb 5	Cast §§	—	—	10.5 to 13.4	19.0 to 23.2	15,000 to 19,000	27,000 to 33,000	20.0 to 16.0	20.0 to 15.0	50 to 62	—
Cu 83, Sn 14, Zn 2, Pb 1	Cast	—	—	10.5 to 13.4	16.2 to 19.0	15,000 to 19,000	23,000 to 27,000	4.0 to 0.5	4.0 to 0.5	— —	20 24
Zinc, Phosphor ("Non Gran")											
Cu 86, Sn 11, Zn 3, Ptr.	Cast	—	—	13.0	25.0	19,000	35,000	9.0	—	—	—
Vanadium, See Brass, Vanadium.											
Copper, Aluminum or Aluminum Bronze:											
Cu 90, Al 10	Cast, sand ‖ ‖	7.5–7.45	468–465	13.9 to 23.3	51.1 to 60.0	19,800 to 33,200	72,700 to 85,500	28.8 to 21.7	30.0 to 22.4	102 to 106	25 to 26
Cu 92.5, Al 7.2	Rolled, and ann.	—	—	7.0	37.5	9,600	53,500	91.0	72.9	81	19
Aluminum, Iron or Sillman bronze	Wrought	—	—	9.8	59.3	14,000	84,400	11.5	—	—	—
	Cast	—	—	8.1	55.5	11,500	78,850	14.5	—	—	—
Cu 86.4, Al 9.7, Fe 3.9	Cast, sand	—	—	14.0	54.0	20,000	77,000	24.5	25.0	100	—
Cu 88.5, Al 10.5, Fe 1.0	Quenched 850° C drawn 700° C.	—	—	28.0	65.0	40,000	92,000	14.0	18.5	140	—

* Gov't. Bronze: Cu 88, Sn 10, Zn 2 (values shown are averages for 30 specimens from five foundries tested at the Bureau of Standards).

† Compressive P-limit 10.5 kg/mm² or 15,000 lb/in² with 29 per cent set for 70 kg/mm² or 100,000 lb/in² load.

‡ Values from same series of tests as first values for "88–10–2," averages for 26 specimens from five foundries tested at Bureau of Standards.

§ Compressive P-limit 9.1 kg/mm² or 13,000 lb/in² with 34 per cent set for 70 kg/mm² or 100,000 lb/in² load.

‖ Specification minimums: U. S. Navy 46B17, Dec. 2, 1918, for hot-rolled aluminum bronze, Cu 85 to 87, Al 7 to 9, Fe 2.5 to 4.5. Specification values under P-limit are for yield point.

¶ Two and six tenths per cent increase in strength up to 762 mm (30 in.) width.

** Compressive P-limit: cast, 14.1 kg/mm² or 20,000 lb/in² with 11.4 per cent set at 70 kg/mm² or 100,000 lb/in² load.

†† Compressive P-limit: cast, 12.7 to 14.1 kg/mm² or 18,000 to 20,000 lb/in² with 13 to 15 per cent set at 700 kg/mm² or 100,000 lb/in² load.

‡‡ Modulus of elasticity 14,800 kg/mm² or 21,150,000 lb/in²

§§ Compressive P-limit 8.4 kg/mm² or 12,000 lb/in² with 36 per cent set for 70.3 kg/mm², or 100,000 lb/in² load.

‖ ‖ High values are after Jean Escard "L'Aluminum dans L'Industrie," Paris, 1918. Compressive P-limit 13.5 kg/mm² or 19,200 lb/in² with 13.5 per cent set for 70.3 kg/mm² or 100,000 lb/in² load.

Table 70

MECHANICAL PROPERTIES

Miscellaneous Metals and Alloys

Metal or alloy. Approx. composition, per cent.	Condition.	Density or weight. gm per cm³	Density or weight. lb. per ft³	P-limit. Tension, kg/mm²	Ultimate strength. Tension, kg/mm²	P-limit. Tension, lb/in²	Ultimate strength. Tension, lb/in²	Elong. in 50.8 mm (2 in.). Per cent.	Reduct. of area. Per cent.	Hardness. Brinell @ 500 kg	Hardness. Scleroscope.
* **Cobalt**, Co 99.7	Cast	8.8	550	—	23.1	—	33,000	—	—	121	—
	Ann.	8.9	556	—	26.0	—	37,000	—	—	48	—
Gold, Au 100	Cast	19.3	1203	—	18.0	—	25,000	25.0	—	—	20
	Drawn hard	—	—	—	26.0	—	37,000	—	—	—	—
Copper, Au 90, Cu 10	Drawn hard	17.2	1073	—	45.8	—	65,100	—	—	—	—
Copper, Silver, Au 58, Cu 30 Ag 12	Drawn hard	—	—	—	102.0	—	145,000	—	—	—	—
Lead, Pb†	Cast	11.38	710	—	1.3	—	1,780	—	—	8	3
(Comm'c'l.)	Rolled hard	11.40	711	—	2.3	—	3,300	—	—	—	—
	Drawn soft	—	—	—	1.7	—	2,420	—	—	—	—
	Drawn hard	—	—	—	2.2	—	3,130	—	—	—	—
Antimony ‡ Pb 95.5, Sb 4.5	Cast	10.5	655	2.8	4.5	4,000	6,400	—	—	—	—
Magnesium, Mg	Drawn hard	1.7	106	—	21.0	—	30,000	—	—	—	—
		1.74	109	—	23.2	—	33,000	—	—	—	—
Nickel, Ni 98.5	Cast	8.3	518	16.7 **	26.7	23,800 **	38,000	5.7	6.1	76	—
Ni 99.95	Wrought, ann.	8.7	543	12.6	29.9	17,900	42,500	11.0	—	—	—
Ni 98.5	Wrought, com.	—	—	—	46.0	—	65,000	—	—	83	35
Ni	Rolled hard, "	—	—	—	64.7	—	92,000	11.0	—	—	—
Ni	Rolled ann. "	—	—	—	53.4	—	76,000	35.0	—	—	—
Ni	Drawn hard, D = 1.65 mm or 0.065 in.	—	—	—	109.0	—	155,000	—	—	—	—
Copper, iron, manganese or Monel metal:											
Ni 67, Cu 28, Fe 3, Mn 2	Cast	8.9	555	21.2	49.3	30,100	70,000	18.0	20.0	—	21
	Rolled	—	—	55.1	73.8	78,400	104,900	31.3	61.7	—	27
Ni 66, Cu 28, Fe 3.5, Mn 2.5	Wrought	—	—	28.3	64.8	40,300	92,200	46.3	70.2	—	—
Ni 71, Cu 27, Fe 2 §	Drawn hard	—	—	—	112.5	—	160,000	—	—	—	—
46 M1a ‖	Cast, minimums	—	—	22.8 **	45.7	32,500 **	65,000	25.0	—	—	—
46 M 7b ‖	Rolled, min., rods and bars ¶	—	—	28.1 **	56.2	40,000 **	80,000	32.0	—	—	—
‖	Rolled, minimum, sheets and plates	—	—	21.1	45.7	30,000	65,000	15.0	—	—	—
Palladium, Pd	Drawn hard	12.1	755	—	27.0	—	39,000	—	—	—	—
Platinum, Pt	Drawn hard	21.5	1342	—	37.3	—	53,000	18.0	—	—	24
	Drawn ann.	—	—	—	24.6	—	35,000	50.0	—	—	13
Silver, Ag 100	Cast	10.5	655	—	28.1	—	40,000	—	—	—	—
	Drawn hard	10.57	660	—	36.0	—	51,200	—	—	59	32
Copper, Ag 75, Cu 25	Drawn hard	—	—	—	77.0	—	109,500	—	—	—	—
Tantalum, Ta	Drawn hard	16.6	1035	—	91.0	—	130,000	—	—	—	—
Tin, Sn 99.8††	Cast	7.3	456	1.1	2.8	1,600	4,000	35.0	—	14	8
	Rolled	—	—	—	3.7	—	5,300	—	—	—	—
	Drawn hard	—	—	—	7.0	—	10,000	—	—	—	—
Antimony, Copper, Zinc (Britannia Metal): Sn 81, Sb 16, Cu 2, Zn 1.											
Zinc, **Aluminum**, etc. (aluminum solder):											
Sn 63, Zn 18, Al 13, Cu 3, Sb 2, Pb 1	Cast	—	—	—	10.2	—	14,500	1.9	1.5	—	—
Sn 62, Zn 15, Al 11, Pb 8, Cu 3, Sb 1	Cast	—	—	—	9.1	—	13,000	1.6	1.3	—	—
Zinc, aluminum: Sn 86, Zn 9, Al 5	Cast, chill	—	—	—	8.6	—	12,200	41.0	81.0	—	—
Aluminum, zinc, cadmium: Sn 78, Al 9, Zn 8, Cd 5	Cast, chill	—	—	—	10.1	—	14,300	18.0	41.0	—	—

Antimony: Modulus of Elasticity 7960 kg/mm² or 11,320,000 lb/in² (Bridgman).

* Compressive strength: cast and annealed, 86.0 kg/mm² or 122,000 lb/in²

Comm'c'l. comp., C 0.06, cast, tensile, ultimate, 42.8 kg/mm² or 61,000 lb/in², with 20 per cent elongation in 50.8 or 2 in. Compression, ultimate 123.0 kg/mm² or 175,000 lb/in²

Stellite, Co 59.5, Mo 22.5, Cr 10.8, Fe 3.1, Mn 2.0, C 0.9, Si 0.8. Brinell hardness 512 at 3000 kg, density 8.3

† Modulus of elasticity, cast or rolled, 492 kg/mm² or 700,000 lb/in²; drawn hard 703 kg/mm² or 1,000,000 lb/in

‡ For compressive test data on lead-base babbitt metal, see table following zinc.

§ Modulus of elasticity 15,800 kg/mm² or 22,500,000 lb/in²

‖ Specification values, U. S. Navy, Monel metal, Ni min. 60, Cu min. 23, Fe max. 3.5, Mn max. 3.5, C + Si max 0.8, Al max. 0.5.

¶ Values shown are subject to slight modifications dependent on shapes and thicknesses.

** Values are for yield point.

†† Compressive strength: cast, 4.5 kg/mm² or 6,400 lb/in²

Modulus of elasticity: cast av. 2,810 kg/mm² or 4,000,000 lb/in²; rolled av. 401.0 kg/mm² or 5,700,000 lb/in²

TABLE 71

MECHANICAL PROPERTIES

Miscellaneous Metals and Alloys

(*a*) TUNGSTEN AND ZINC

Metal or alloy approx. comp. per cent.	Condition.	Density or weight. gm per cm^3	Density or weight. lb. per ft^3	P-limit. Tension, kg/mm^2	Ultimate strength. Tension, kg/mm^2	P-limit. Tension, lb/in^2	Ultimate strength. Tension, lb/in^2	Elong. in 50.8 mm (2 in.). Per cent	Reduct. of area. Per cent	Hardness. Brinell @ 500 kg	Hardness. Sclero-scope.
Tungsten, W 99.2 *	Ingot sintered, D = 5.7 mm or 0.22 in.	18.0	1124	—	12.7	—	18,000	0.0	0.0	—	—
	Swaged rod, D = 0.7 mm or 0.03 in.	—	—	—	151.0	—	215,000	4.0	28.0	—	—
	Drawn hard, D = 0.029 mm or 0.00114 in.	—	—	—	415.0	—	590,000	—	65.0	—	—
	Swaged and drawn hot 97.5% reduction†...	—	—	—	164.0	—	233,500	3.2	14.0	—	—
	Same as above and equiaxed at 2000°C in H_2‡............	—	—	—	118.0	—	168,000	0.0	0.0	—	—
Zinc, §Zn.	Cast...............	7.0	437	(Impurities Pb, Fe and Cd)				—	—	—	—
	Coarse crystalline....	—	—	—	2.8 to	—	4,000 to	—	—	42 to	8 to
	Fine crystalline......	—	—	—	8.4	—	12,000	—	—	48	10
	Rolled (with grain or direction of rolling).	—	—	2.0	19.0	2,900	27,000	—	—	—	—
	Rolled (across grain or direction of rolling).	—	—	4.1	25.3	5,800	36,000	—	—	—	—
	Drawn hard.........	7.1	443	—	7.0	—	10,000	—	—	—	—

* Commercial composition for incandescent electric lamp filaments containing thoria (ThO_2) approx. 0.75 per cent after Z Jeffries Am. Inst. Min. Eng. Bulletin 138, June, 1918.

† After Z Jeffries Am. Inst. Min. Eng. Bulletin 149, May, 1919.

‡ Ordinary annealing treatment makes W brittle, and severe working, below recrystallization or equiaxing temperature, produces ductility W rods which have been worked and recrystallized are stronger than sintered rods. The equiaxing temperature of worked tungsten, with a 5-min. exposure, varies from 2200° C for a work rod with 24 per cent reduction, to 1350° C for a fine wire with 100 per cent reduction. Tungsten wire, D = 0.635 mm or 0.025 in.

§ Compression on cylinder 25.4 mm (1 in.) by 65.1 mm (2.6 in.), at 20 per cent deformation:
For spelter (cast zinc) free from Cd, av. 17.2 kg/mm^2 or 24,500 lb/in^2
For spelter with Cd 0.26, av. 27.4 kg/mm^2 or 39,000 lb/in^2 (See Proc. A. S. T. M., Vol. 13, pl. 19.)
Modulus of rupture averages twice the corresponding tensile strength.
Shearing strength rolled, averages 13.6 kg/mm^2 or 194,000 lb/in^2
Modulus of elasticity cast, 7,750 kg/mm^2 or 11,025,000 lb/in^2
Modulus of elasticity. rolled, 8450 kg/mm^2 or 12,000 000 lb/in^2 (Moore, Bulletin 52, Eng. Exp. Sta. Univ. of Ill.)

(*b*) WHITE METAL BEARING ALLOYS (BABBITT METAL)

A. S. T. M. vol. xviii, I, p. 491.

Experimental permanent deformation values from compression tests on cylinders 31.8 mm (1¼ in.) diam. by 63.5 mm (2½ in.) long, tested at 21° C (70° F.) (Set readings after removing loads.)

Alloy No.	Formula, per cent. Sn	Sb	Cu	Pb	Pouring temp. C	F.	Weight. g/cm^3	$lb./ft^3$	Permanent deformation @ 21° C: @ 454 kg = 1000 lb. mm	in.	@ 2268 kg = 5000 lb. mm	in.	@ 4536 kg = 10,000 lb. mm	in.	Hardness. Brinell @ 21° C	@ 500 kg @ 100° C
	Tin Base.															
1	91.0	4.5	4.5	—	440	824	7.34	458	0.000	0.0000	0.025	0.0010	0.380	0.0150	28.6	12.8
2 *	89.0	7.5	3.5	—	432	808	7.39	461	.000	.0000	.038	.0015	.305	.0120	28.3	12.7
3	83.3	8.3	8.3	—	491	916	7.46	465	.025	.0010	.114	.0045	.180	.0070	34.4	15.7
4	75.0	12.0	3.0	10.0	360	680	7.52	469	.013	.0005	.064	.0025	.230	.0090	29.6	12.8
5	65.0	15.0	2.0	18.0	350	661	7.75	484	.025	.0010	.076	.0030	.230	.0090	29.6	11.8
	Lead Base.															
6	20.0	15.0	1.5	63.5	337	638	9.33	582	.038	.0015	.127	.0050	.457	.0180	24.3	11.1
7	10.0	15.0	—	75.0	329	625	9.73	607	.025	.0010	.127	.0050	.583	.0230	24.1	11.7
8	5.0	15.0	—	80.0	329	625	10.04	627	.051	.0020	.229	.0090	1.575	.0620	20.9	10.3
9	5.0	10.0	—	85.0	319	616	10.24	640	.102	.0040	.305	.0120	2.130	.0840	19.5	8.6
10	2.0	15.0	—	83.0	325	625	10.07	629	.025	.0010	.254	.0100	3.910	.1540	17.0	8.9
11	—	15.0	—	85.0	325	625	10.28	642	.025	.0010	.254	.0100	3.020	.1190	17.0	9.9
12	—	10.0	—	90.0	334	634	10.67	666	0.064	0.0025	0.432	0.0170	7.240	0.2850	14.3	6.4

* U S Navy Spec. 46M2b (Cu 3 to 4.5, Sn 88 to 89.5, Sb 7.0 to 8.0) covers manufacture of anti-friction-metal castings. (Composition W.)

NOTE. — *See also* Brass, Lead (yellow brass), Brass, Lead-Tin (Red Brass); Bronze, Phosphor, etc., under Copper alloys

TABLE 72
MECHANICAL PROPERTIES
Cement and Concrete

(*a*) CEMENT

CEMENT: Specification Values (A. S. T. M. C9 to 17, C10 to 09, and C9 to 16T). Minimum strengths based on tests of 645 mm² (1 in²) cross section briquettes for tension, and cylinders 50.8 mm (2 in.) diameter by 101.6 mm (4 in.) length for compression. Mortar composed of 1 part cement to 3 parts Ottawa sand by volume; specimens kept in damp closet for first 24 hours and in water from then on until tested.

Cement (1: 3 mortar tested).	Specific gravity.	Age, days.	Tension.		Compression.	
			kg/mm²	lb/in²	kg/mm²	lb/in²
Std. Portland	3.10	7	0.16	200	0.85	1,200
White Portland	3.07	28	.24	300	1.60	2,000
Natural Av.	2.85	7	.03	50	—	—
Natural	—	28	0.09	125	—	—

(*b*) CEMENT AND CEMENT MORTARS

CEMENT AND CEMENT MORTARS.— Bureau of Standards Experimental Values. Compressive Strengths of Portland cement mortars of uniform plastic consistency. Data from tests on 50.8 mm (2 in.) cubes stored in water. Sand: Potomac River, representative concrete sand.

Cement.	Sand.	Water, per cent.	Age, days.	Compressive strength.	
Proportions by volume.				kg/mm²	lb/in²
1	0	30.0	7	4.20	5,970
			28	6.40	9,120
1	1	16.0	7	3.10	4,440
			28	4.75	6,750
1	2	13.6	7	2.05	2,900
			28	3.10	4,440
1	3	13.9	7	1.25	1,780
			28	2.05	2,890
1	9	15.1	7	0.10	120
			28	0.15	200

NOTE.— (From Bureau of Standards Tech. Paper 58.) **Neat cement** briquettes mixed at plastic consistency (water 21 per cent) show 0.52 kg/mm² or 740 lb/in² tensile strength at 28 days' age;

1 **Cement:** 3 **Ottawa sand-mortar** briquettes, mixed at plastic consistency (water 9 per cent) show 0.28 kg/mm² or 400 lb/in² tensile strength at 28 days' age.

Table 72 (*continued*)

MECHANICAL PROPERTIES

(*c*) Concrete

Concrete: Compressive strengths. Experimental values for various mixtures. Results compiled by Joint Committee on Concrete and Reinforced Concrete. Final Report adopted by the Committee July 1, 1916. Data are based on tests of cylinders 203.2 mm (8 in.) diameter and 406.4 mm (16 in.) long at 28 days age.

American Standard Concrete Compressive Strengths.

Aggregate.	Units.	Mix.				
		1:3	1:4½	1:6	1:7½	1:9
Granite, trap rock	kg/mm^2	2.3	2.0	1.5	1.3	1.0
	lb/in^2	3300	2800	2200	1800	1400
Gravel, hard limestone and hard sandstone	kg/mm^2	2.1	1.8	1.4	1.1	0.9
	lb/in^2	3000	2500	2000	1600	1300
Soft limestone and soft sandstone	kg/mm^2	1.5	1.3	1.1	0.8	0.7
	lb/in^2	2200	1800	1500	1200	1000
Cinders	kg/mm^2	0.6	0.5	0.4	0.4	0.3
	lb/in^2	800	700	600	500	400

Note. — Mix shows ratio of cement (Portland) to combined volume of fine and coarse aggregate (latter as shown).

Committee recommends certain fractions of tabular values as safe working stresses in reinforced concrete design, which may be summarized as follows:
Bearing, 35 per cent of compressive strength;
Compression, extreme fiber, 32.5 per cent of compressive strength;
Vertical shearing stress 2 to 6 per cent of compressive strength, depending on reinforcing;
Bond stress, 4 and 5 per cent of compressive strength, for plain and deformed bars, respectively.

Modulus of Elasticity to be assumed as follows:

For concrete with strength.		Assume modulus of elasticity.	
kg/mm^2	lb/in^2	kg/mm^2	lb/in^2
up to 0.6	up to 800	530	750,000
0.6 to 1.5	800 to 2200	1400	2,000,000
1.5 to 2.0	2200 to 2900	1750	2,500,000
over 2.0	over 2900	2100	3,000,000

(See Joint Committee Report, Proc. A. S. T. M. v. XVII, 1917, p. 201.)

Editor's Note. — The values shown in the table above are probably fair values for the compressive strengths of concretes made with average commercial material, although higher results are usually obtained in laboratory tests of specimens with high grade aggregates. Observed values on 1 : 2 : 4 gravel concrete show moduli of elasticity up to 3160 kg/mm^2 or 4,500,000 lb/in^2 and compressive strengths to 4.2 kg/mm^2 or 6000 lb/in^2

Tensile strengths average 10 per cent of values shown from compressive strengths.

Shearing strengths average from 75 to 125 per cent of the compressive strengths; the larger percentage representing the shear of the leaner mixtures (for direct shear, Hatt gives 60 to 80 per cent of crushing strength).

Compressive strengths of natural cement concrete average from 30 to 40 per cent of that of Portland cement concrete of the same proportioned mix.

Transverse strength: modulus of rupture of 1 : 2½ : 5 concrete at 1 and 2 months equal to one sixth crushing strength at same age (Hatt).

Weight of granite, gravel and limestone, 1 : 2 : 4 concretes averages about 2.33 g/cm^3 or 145 lb/ft^3; that of cinder concrete of same mix is about 1.85 g/cm^3 or 115 lb/ft^3

Concrete, 1 : 2 : 4 Mix, Compressive Strengths at Various Ages.

Experimental Values: one part cement, two parts Ohio River sand and four parts of coarse aggregate as shown. Compressive tests made on 203.2 mm (8 in.) diameter cylinders, 406.4 mm (16 in.) long. (After Pittsburgh Testing Laboratory Results. *See Rwy Age*, vol. 64, Jan. 18, 1918, pp. 165–166.)

Coarse aggregate.	Unit.	Age.			
		14 days.	30 days.	60 days.	180 days.
Gravel	kg/mm^2	1.35	1.61	2.06	2.67
	lb/in^2	1921	2294	2925	3798
Limestone	kg/mm^2	1.24	1.53	2.35	3.11
	lb/in^2	1758	2174	3343	4426
Trap rock	kg/mm^2	1.45	1.67	2.36	3.39
	lb/in^2	2063	2386	3360	4819
Granite	kg/mm^2	1.49	1.61	2.14	2.92
	lb/in^2	2122	2292	3043	4151
Slag No. 1	kg/mm^2	1.75	2.16	2.37	3.38
	lb/in^2	2484	3075	3365	4803
Slag No. 2	kg/mm^2	1.37	1.78	2.06	2.64
	lb/in^2	1941	2525	2930	3753

Note. — Maximum and minimum test results varied about 5 per cent above or below average values shown above.

Table 73
MECHANICAL PROPERTIES
Stone and Clay Products

(a) Strength and Stiffness of American Building Stones *

Stone.	Weight, average.		Compression. Ultimate strength.			Flexure. Modulus of rupture.			Shear. Ultimate strength.			Flexure. Modulus of elasticity.		
			Average.		Range per cent.	Average.		Range per cent.	Average.		Range per cent.	Average.		Range per cent.
	g/cm³	lb/ft³	kg/mm²	lb/in²		kg/mm²	lb/in²		kg/mm²	lb/in²		kg/mm²	lb/in²	
Granite...	2.6	165	14.20	20,200	25	1.15	1600	30	1.60	2300	20	5300	7,500,000	25
Marble...	2.7	170	8.85	12,600	25	1.05	1500	50	0.90	1300	25	5750	8,200,000	50
Limestone	2.6	160	6.30	9,000	95	0.85	1200	100	1.00	1400	45	5900	8,400,000	65
Sandstone.	2.2	135	8.80	12,500	50	1.05	1500	55	1.20	1700	45	2300	3,300,000	100

* Values based on tests of American building stones from upwards of twenty-five localities, made at Watertown (Mass.) Arsenal (Moore, p. 184). Each value shown under "Range" is one half the difference between maximum and minimum locality averages expressed as a percentage of the average for the stone.

(b) Strength and Stiffness of Bavarian Building Stones *

Stone.	Weight, average.		Compression. Ultimate strength.			Flexure. Modulus of rupture.			Shear. Ultimate Strength.†			Flexure. Modulus of elasticity.		
			Average.		Range per cent.	Average.		Range per cent.	Average.		Range per cent.	Average.		Range per cent
	g/cm³	lb/ft³	kg/mm²	lb/in²		kg/mm²	lb/in²		kg/mm²	lb/in²		kg/mm²	lb/in²	
Granite..	2.66	165	13.70	19,500	5	0.90	1300	5	1.00	1420	0	1600	2,300,000	30
Marble ‡.	2.16	135	5.60	8,000	15	0.30	450	—	0.45	620	50	3450	4,900,000	—
Limestone	2.48	155	8.10	11,500	5	1.10	1550	45	0.60	870	20	2350	3,350,000	90
Sandstone	2.30	145	8.10	11,500	75	0.45	650	55	0.50	680	35	2500	3,550,000	35

* Values based on careful tests by Bauschinger, "Communications," Vol. 10.
† Shearing strength determined perpendicular to bed of stone.
‡ Values are for Jurassic limestone.

General Notes. — 1. Later transverse strength (flexure) tests on Wisconsin building stones (Johnson's "Materials of Construction," 1918 ed., p. 255) show moduli of rupture as follows: Granite, 1.90 to 2.75 kg/mm² or 2710 to 3910 lb/in²; limestone, 0.80 to 3.30 kg/mm² or 1160 to 4660 lb/in²; sandstone, 0.25 to 0.95 kg/mm² or 360 to 1320 lb/in².
2. Good slate has a modulus of rupture of 4.90 kg/mm² or 7000 lb/in² (*loc. cit.*, p. 257).

MECHANICAL PROPERTIES

Stone and Clay Products

(*c*) STRENGTH OF AMERICAN BUILDING BRICKS *

Brick — description.	Absorption average per cent.	Compression. Min. ult. strength.		Flexure. Min. modulus rupture.	
		kg/mm²	lb/in²	kg/mm²	lb/in²
Class A (Vitrified)	5	3.50	5000	0.65	900
Class B (Hard burned)	12	2.45	3500	0.40	600
Class C (Common firsts)	18	1.40	2000	0.30	400
Class D (Common)	—	1.05	1500	0.20	300

* After A. S. T. M. Committee C–3, Report 1913, and University laboratories' tests for Committee C–3 (Johnson, p. 281).

(*d*) STRENGTH IN COMPRESSION OF BRICK PIERS AND OF TERRA-COTTA BLOCK PIERS

Tabular values are based on test data from Watertown Arsenal, Cornell University, U. S. Bureau of Standards, and University of Ill. (Moore, p. 185).

Brick or block used.	Mortar.	Compression.* Av. ult. strength.	
		kg/mm²	lb/in²
Vitrified brick	1 part P.† cement : 3 parts sand	1.95	2800
Pressed (face) brick	1 part P. cement : 3 parts sand	1.40	2000
Pressed (face) brick	1 part lime : 3 parts sand	1.00	1400
Common brick	1 part P. cement : 3 parts sand	0.70	1000
Common brick	1 part lime : 3 parts sand	0.50	700
Terra-cotta brick	1 part P. cement : 3 parts sand	2.10	3000

* Building ordinances of American cities specify allowable working stresses in compression over bearing area of 12.5 per cent (vitrified brick) to 17.5 per cent (common brick) of corresponding ultimate compressive strength shown in table.

† P. denotes Portland.

(*e*) STRENGTH OF COMPRESSION OF VARIOUS BRICKS

Reasonable minimum average compressive strengths for other types of brick than building brick are noted by Johnson, "Materials of Construction," pp. 289 ff., as follows:

Brick.	kg/mm²	lb/in²
sand-lime	2.10	3000
sand-lime (German)	1.53	2180 (av. 255 tests)
paving	5.60	8000
acid-refractory	0.70	1000
silica-refractory	1.40	2000

The specific gravity of brick ranges from 1.9 to 2.6 (corresponding to 120 to 160 lb/ft³).

Building tile: hollow clay blocks of good quality, — minimum compressive strength: 0.70 kg/mm² or 1000 lb/in². Tests made for A. S. T. M. Committee C–10 (A. S. T. M. Proc. XVII, I, p. 334) show compressive strengths ranging from 0.45 to 8.70 kg/mm² or 640 to 12,360 lb/in² of net section, corresponding to 0.05 to 4.20 kg/mm² or 95 to 6000 lb/in² of gross section. Recommended safe loads (Marks, "Mechanical Engineers' Handbook," p. 625) for effective bearing parts of hollow tile: hard fire-clay tiles 0.06 kg/mm² or 80 lb/in²; ordinary clay tiles 0.04 kg/mm² or 60 lb/in²; porous terra-cotta tiles 0.03 kg/mm² or 40 lb/in.² The specific gravity of tile ranges from 1.9 to 2.5 corresponding to a weight of 120 to 155 lb/ft³.

TABLE 74
MECHANICAL PROPERTIES
Rubber and Leather

(a) RUBBER, SHEET *

Grade.	Ultimate strength.				Ult. elongation.		Set.‡	
	Longitudinal.†		Transverse.		Longit.	Transv.	Longit.	Transv.
	kg/mm²	lb/in²	kg/mm²	lb/in²	Per cent.		Per cent.	
1	1.92	2730	1.81	2575	630	640	11.2	7.3
2	1.45	2070	1.43	2030	640	670	6.0	5.0
3	0.84	1200	0.89	1260	480	555	22.1	16.3
4	1.30	1850	1.20	1700	410	460	34.0	24.0
5	0.48	690	0.36	510	320	280	27.5	25.0
6	0.62	880	0.48	690	315	315	34.3	25.9

* Data from Bureau of Standards Circular 38.
† Longitudinal indicates direction of rolling through the calendar.
‡ Set measured after 300 per cent elongation for 1 minute with 1 minute rest.

The specific gravity of rubber averages from 0.95 to 1.25, corresponding to an average weight of 60 to 80 lb/ft³.

Four-ply rubber belts show an average ultimate tensile strength of 0.63 to 0.65 kg/mm² or 890 to 930 lb/in² (Benjamin), and a working tensile stress of 0.07 to 0.11 kg/mm² or 100 to 150 lb/in² is recommended (Bach).

(b) LEATHER, BELTING

Oak tanned leather from the center or back of the hide:

Minimum tensile strengths of belts (Marks, p. 622) $\begin{cases} \text{single 2.8 kg/mm}^2 \text{ or 4000 lb/in}^2 \\ \text{double 2.5 kg/mm}^2 \text{ or 3600 lb/in}^2 \end{cases}$

Maximum elongation for one hour application of 1.6 kg/mm² or 2250 lb/in² stress $\begin{cases} \text{single 13.5 per cent} \\ \text{double 12.5 per cent} \end{cases}$

Modulus of elasticity of leather varies from an average value of 12.5 kg/mm² or 17,800 lb/in² (new) to 22.5 kg/mm² or 32,000 lb/in² (old).

Chrome leather has a tensile strength of 6.0 to 9.1 kg/mm² or 8500 to 12,900 lb/in².

The specific gravity of leather varies from 0.86 to 1.02, corresponding to a weight of 53.6 to 63.6 lb./ft³.

Table 75
MECHANICAL PROPERTIES
Manila Rope

Manila Rope, Weight and Strength — Specification Values. From U. S. Government Standard Specifications adopted April 4, 1918.

Rope to be made of manila or Abaca fiber with no fiber of grade lower than U. S. Government Grade I, to be three-strand,* medium-laid, with maximum weights and minimum strengths shown in the table below, lubricant content to be not less than 8 nor more than 12 per cent of the weight of the rope as sold.

Approximate diameter.		Circumference.		Maximum net weight.		Minimum breaking strength.	
mm	in.	mm	in.	kg/m	lb/ft.	kg	lb.
6.3	1/4	19.1	3/4	0.029	0.0196	320	700
7.9	5/16	25.4	1	0.044	0.0286	540	1,200
9.5	3/8	28.6	1 1/8	0.061	0.0408	660	1,450
11.1	7/16	31.8	1 1/4	0.080	0.0539	790	1,750
11.9	15/32	34.9	1 3/8	0.095	0.0637	950	2,100
12.7	1/2	38.1	1 1/2	0.109	0.0735	1,110	2,450
14.3	9/16	44.5	1 3/4	0.153	0.1029	1,430	3,150
15.9	5/8	50.8	2	0.195	0.1307	1,810	4,000
19.1	3/4	57.2	2 1/4	0.241	0.1617	2,220	4,900
20.6	13/16	63.5	2 1/2	0.284	0.1911	2,680	5,900
22.2	7/8	69.9	2 3/4	0.328	0.2205	3,170	7,000
25.4	1	76.2	3	0.394	0.2645	3,720	8,200
27.0	1 1/16	82.6	3 1/4	0.459	0.3087	4,310	9,500
28.6	1 1/8	88.9	3 1/2	0.525	0.3528	4,990	11,000
31.8	1 1/4	95.2	3 3/4	0.612	0.4115	5,670	12,500
33.3	1 5/16	101.6	4	0.700	0.4703	6,440	14,200
34.9	1 3/8	108.0	4 1/4	0.787	0.5290	7,260	16,000
38.1	1 1/2	114.3	4 1/2	0.875	0.5879	7,940	17,500
39.4	1 9/16	120.7	4 3/4	0.984	0.6615	8,840	19,500
41.2	1 5/8	127.0	5	1.094	0.7348	9,750	21,500
44.5	1 3/4	140.0	5 1/2	1.312	0.8818	11,550	25,500
50.8	2	152.4	6	1.576	1.059	13,610	30,000
52.4	2 1/16	165.1	6 1/2	1.823	1.225	15,420	34,000
57.2	2 1/4	177.8	7	2.144	1.441	17,460	38,500
63.5	2 1/2	190.5	7 1/2	2.450	1.646	19,730	43,500
66.7	2 5/8	203.2	8	2.799	1.881	22,220	49,000
73.0	2 7/8	215.9	8 1/2	3.136	2.107	24,940	55,000
76.2	3	228.6	9	3.543	2.381	27,670	61,000
79.4	3 1/8	241.3	9 1/2	3.936	2.645	30,390	67,000
82.5	3 1/4	254.0	10	4.375	2.940	33,110	73,000

* Four-strand, medium-laid rope when ordered may run up to 7% heavier than three-strand rope of the same size, and must show 95% of the strength required for three-strand rope of the same size.

TABLE 76.—Mechanical Properties of Hardwoods Grown in U. S. (Metric Units)

Common and botanical name.	Specific gravity, oven-dry, based on vol. when green.	Specific gravity, oven-dry, based on vol. oven-dry.	Static bending. P-limit, kg/mm²	Static bending. Modulus of rupture, kg/mm²	Static bending. Modulus of elasticity, kg/mm²	Impact bending. P-limit, kg/mm²	Impact bending. 22.7 kg hammer fall for failure—m.	Compression. Parallel to grain. P-limit kg/mm²	Compression. Parallel to grain. Ultimate. kg/mm²	Compression. Perpendicular to grain P-limit, kg/mm²	Shear. Parallel to grain ult. st. kg/mm²	Tension. Perpendicular to grain ult. st. kg/mm²	Hardness. Load ½ imb… 11.3 m… d. ba… end kg
1	4	5	6	7	8	9	10	11	12	13	14	15	16
Alder, red (*Alnus oregona*)	0.37	0.43	2.65	4.55	830	5.60	0.56	1.85	2.10	0.22	0.54	0.27	250
Ash, black (*Fraxinus nigra*)	0.46	0.53	1.85	4.20	720	5.10	0.81	1.15	1.60	0.31	0.61	0.35	270
Ash, white (forest grown) (*Fraxinus americana*)	0.52	0.60	3.45	6.40	950	8.25	0.91	2.30	2.70	0.57	0.89	0.44	455
Ash, white (second growth) (*Fraxinus americana*)	0.58	0.71	4.30	7.60	1150	9.70	1.19	2.70	2.90	0.56	1.13	0.56	515
Aspen (*Populus tremuloides*)	0.36	0.42	2.05	3.75	590	4.85	0.71	1.10	1.50	0.14	0.44	0.13	120
Basswood (*Tilia americana*)	0.33	0.40	1.90	3.50	725	4.35	0.43	1.20	1.55	0.15	0.43	0.20	125
Beech (*Fagus atropunicea*)	0.54	0.66	3.15	5.80	875	7.30	1.02	1.80	2.30	0.43	0.85	0.56	430
Birch, paper (*Betula papyrifera*)	0.47	0.60	2.05	4.10	710	5.50	1.14	1.20	1.55	0.21	0.56	0.27	180
Birch, yellow (*Betula lutea*)	0.54	0.66	3.25	6.05	1080	8.25	1.02	1.90	2.40	0.32	0.78	0.34	370
Butternut (*Juglans cinerea*)	0.36	0.40	2.05	3.80	680	5.15	0.61	1.40	1.70	0.19	0.53	0.30	185
Cherry, black (*Prunus serotina*)	0.47	0.53	2.95	5.65	920	7.20	0.84	2.10	2.50	0.31	0.80	0.40	340
Chestnut (*Castanea dentata*)	0.40	0.46	2.20	3.95	655	5.55	0.61	1.45	1.75	0.27	0.56	0.30	240
Cottonwood (*Populus deltoides*)	0.37	0.43	2.05	3.75	710	5.05	0.53	1.25	1.60	0.17	0.48	0.29	175
Cucumber tree (*Magnolia acuminata*)	0.44	0.52	2.95	5.20	1100	6.55	0.76	1.95	2.20	0.29	0.70	0.31	270
Dogwood (flowering) (*Cornus florida*)	0.64	0.80	3.40	6.20	830	5.00	1.47	—	2.55	0.73	1.07	—	640
Elm, cork (*Ulmus racemosa*)	0.58	0.66	3.25	6.70	840	7.75	1.27	2.00	2.70	0.53	0.89	0.47	445
Elm, white (*Ulmus americana*)	0.44	0.54	2.55	4.85	725	5.70	0.86	1.60	2.00	0.28	0.65	0.39	275
Gum, blue (*Eucalyptus globulus*)	0.62	0.80	5.35	7.85	1430	10.00	1.02	3.40	3.70	0.72	1.09	0.45	595
Gum, cotton (*Nyssa aquatica*)	0.46	0.52	2.95	5.15	740	6.30	0.76	1.95	2.40	0.42	0.84	0.42	365
Gum, red (*Liquidambar styraciflua*)	0.44	0.53	2.60	4.80	810	7.05	0.84	1.70	1.95	0.32	0.75	0.36	285
Hickory pecan (*Hicoria pecan*)	0.60	0.69	3.65	6.90	960	8.65	1.35	2.15	2.80	0.63	1.04	0.48	575
Hickory, shagbark (*Hicoria ovata*)	0.64	—	4.15	7.75	1105	10.10	1.88	2.40	3.20	0.70	0.93	—	—
Holly, American (*Ilex opaca*)	0.50	0.61	2.40	4.55	630	6.25	1.30	1.40	1.85	0.43	0.80	0.43	390
Laurel, mountain (*Kalmia latifolia*)	0.62	0.74	4.10	5.90	650	7.20	0.81	—	3.00	0.78	1.18	—	635
Locust, black (*Robinia pseudacacia*)	0.66	0.71	6.20	9.70	1300	12.90	1.12	4.40	4.80	1.01	1.24	0.54	740
Locust, honey (*Gleditsia triacanthos*)	0.60	0.67	3.95	7.20	910	8.30	1.20	2.35	3.10	1.00	1.17	0.66	655
Magnolia (evergreen) (*Magnolia foetida*)	0.46	0.53	2.55	4.80	780	6.20	1.37	1.55	1.90	0.40	0.73	0.43	355
Maple, silver (*Acer saccharinum*)	0.44	0.51	2.20	4.10	660	4.80	0.74	1.35	1.75	0.32	0.74	0.39	305
Maple, sugar (*Acer saccharum*)	0.56	0.66	3.50	6.40	1040	8.50	0.91	2.20	2.80	0.53	0.97	0.54	455
Oak, canyon live (*Quercus chrysolepsis*)	0.70	0.84	4.45	7.45	945	7.90	1.20	2.85	3.30	1.04	1.20	0.68	720
Oak, red (*Quercus rubra*)	0.56	0.65	2.60	5.40	910	7.30	1.04	1.65	2.25	0.51	0.79	0.52	465
Oak, white (*Quercus alba*)	0.60	0.71	3.30	5.85	880	7.55	1.07	2.10	2.50	0.59	0.88	0.54	510
Persimmon (*Diospyros virginiana*)	0.64	0.78	3.95	7.05	965	8.50	1.04	2.15	2.95	0.78	1.03	0.54	565
Poplar, yellow (*Liriodendron tulipifera*)	0.37	0.42	2.25	3.95	850	5.65	0.43	1.40	1.80	0.22	0.56	0.32	190
Sycamore (*Platanus occidentalis*)	0.46	0.54	2.30	4.60	745	6.20	0.84	1.70	2.00	0.32	0.71	0.44	320
Walnut, black (*Juglans nigra*)	0.51	0.56	3.80	6.70	1000	8.40	0.94	2.55	3.05	0.42	0.86	0.43	435
Willow, black (*Salix nigra*)	0.34	0.41	1.25	2.75	395	3.60	0.91	0.70	1.05	0.15	0.44	0.30	160

NOTE.— Results of tests on sixty-eight species; test specimens, small clear pieces, 50.8 by 50.8 mm in section, 762 mm for bending; others, shorter. Data taken from Bulletin 556, Forest Service, U. S. Dept. of Agriculture, containing data on 1… tests. See pages 133 and 135 for explanation of columns.

mon and botanical name.	Specific gravity, oven-dry, based on		Static bending.			Impact bending.		Compression.			Shear.	Tension.	Hardness.	
	vol. when green.	vol. oven-dry.	P-limit, kg/mm²	Modulus of rupture, kg/mm²	Modulus of elasticity, kg/mm²	P-limit, kg/mm²	22.7 kg hammer fall for failure — m	Parallel to grain. P-limit. kg/mm²	Parallel to grain. Ultimate. kg/mm²	Perpendicular to grain P-limit, kg/mm²	Parallel to grain ult. st, kg/mm²	Perpendicular to grain ult. st. kg/mm²	Load to ½ imbed 11.3 mm d. ball end kg	Load to ½ imbed 11.3 mm d. ball side kg
1	4	5	6	7	8	9	10	11	12	13	14	15	16	17
incense........... *ocedrus decurrens)*	0.35	0.36	2.75	4.35	590	5.15	0.43	2.00	2.20	0.32	0.58	0.20	260	175
Port Orford,....... *aecyparis lawsoniana)*	0.41	0.47	2.75	4.80	1055	6.55	0.64	2.10	2.30	0.27	0.62	0.17	255	220
western red........ *ija plicata)*	0.31	0.34	2.30	3.65	670	5.05	0.43	1.75	2.00	0.22	0.51	0.15	195	118
white............. *ija occidentalis)*	0.29	0.32	1.85	2.95	450	3.75	0.38	1.00	1.40	0.20	0.44	0.17	145	104
s, bald........... *odium distichum)*	0.41	0.47	2.80	4.80	835	5.60	0.61	2.20	2.45	0.33	0.58	0.20	215	175
nabilis............ *es amabilis)*	0.37	0.42	2.75	4.45	915	5.50	0.53	1.70	2.00	0.22	0.47	0.17	165	140
lsam.............. *es balsamea)*	0.34	0.41	2.10	3.45	675	4.85	0.41	1.55	1.70	0.15	0.43	0.23	135	135
ouglas (1)......... *udotsuga taxifolia)*	0.45	0.52	3.50	5.50	1110	6.60	0.63	2.40	2.80	0.37	0.64	0.14	230	215
ouglas (2)......... *udotsuga taxifolia)*	0.40	0.44	2.55	4.50	830	6.40	0.51	1.80	2.10	0.32	0.62	0.25	205	180
and............... *es grandis)*	0.37	0.42	2.55	4.30	915	5.70	0.56	1.90	2.10	0.24	0.53	0.16	190	165
ble............... *es nobilis)*	0.35	0.41	2.40	4.00	900	5.55	0.51	1.70	1.90	0.22	0.49	0.13	135	115
ite............... *es concolor)*	0.35	0.44	2.75	4.20	795	5.05	0.46	1.85	1.95	0.31	0.51	0.18	175	150
ck, eastern......... *ga canadensis)*	0.38	0.44	2.95	4.70	790	5.55	0.51	1.90	2.30	0.35	0.62	0.18	230	185
ck, western......... *ga heterophylla)*	0.38	0.43	2.40	4.30	835	5.50	0.51	1.60	2.05	0.25	0.57	0.18	245	195
western........... *ix occidentalis)*	0.48	0.59	3.25	5.25	950	6.60	0.61	2.30	2.70	0.39	0.65	0.16	215	205
Cuban............. *us heterophylla)*	0.58	0.68	3.95	6.20	1150	7.95	0.94	2.80	3.15	0.41	0.72	0.20	260	285
oblolly .... *us taeda)*	0.50	0.59	3.10	5.30	970	6.70	0.81	2.00	2.50	0.39	0.63	0.20	185	205
odgepole........... *us contorta)*	0.38	0.44	2.10	3.85	760	5.05	0.51	1.50	1.85	0.22	0.49	0.15	145	150
ongleaf .... *us palustris)*	0.55	0.64	3.80	6.10	1150	7.60	0.86	2.70	3.10	0.42	0.75	0.20	250	270
Norway............ *us resinosa)*	0.44	0.51	2.60	4.50	970	5.35	0.71	1.75	2.20	0.25	0.55	0.13	165	155
itch............... *us rigida)*	0.47	0.54	2.60	4.70	790	6.40	0.74	1.50	2.15	0.36	0.67	0.25	210	220
hortleaf........... *us echinata)*	0.50	0.58	3.15	5.65	1020	7.90	0.99	2.50	2.70	0.34	0.63	0.23	220	255
ugar.............. *us lambertiana)*	0.36	0.39	2.30	3.75	685	4.70	0.43	1.65	1.85	0.25	0.50	0.19	150	145
vestern white....... *us monticola)*	0.39	0.45	2.45	4.00	935	5.35	0.58	1.95	2.15	0.21	0.50	0.18	150	150
vestern yellow....... *us ponderosa)*	0.38	0.42	3.20	3.65	710	4.70	0.48	1.45	1.75	0.24	0.48	0.20	140	145
vhite.............. *us strobus)*	0.36	0.39	2.40	3.75	750	4.55	0.46	1.65	1.90	0.22	0.45	0.18	135	135
, red.............. *ea rubens)*	0.48	0.41	2.40	4.00	830	5.05	0.46	1.65	1.95	0.25	0.54	0.15	190	160
, Sitka .... *ea sitchensis)*	0.34	0.37	2.10	3.85	830	5.05	0.74	1.60	1.85	0.23	0.55	0.16	195	170
ack............... *ix laricina)*	0.49	0.56	2.95	5.05	875	5.50	0.71	2.20	2.45	0.34	0.66	0.18	180	170
vestern............ *us brevifolia)*	0.60	0.67	4.55	7.10	695	9.20	0.97	2.40	3.25	0.73	1.14	0.32	610	520

OTE. — The data above are extracted from tests on one hundred and twenty-six species of wood made at the Forest Products ory, Madison, Wisconsin. Bulletin 556 records results of tests on air-dry timber also, but only data on green timber are shown, tter are based on a larger number of tests and on tests which are not influenced by variations in moisture content. The of dry material usually exceeds that of green material, but allowable working stresses in design should be based on strengths timber, inasmuch as the increase of strength due to drying is a variable, uncertain factor and likely to be offset by defects. specimens were two inches square, by lengths as shown.

COLUMN NOTES. — **2**, Locality where grown, — see Tables 78 and 79; **3**, Moisture includes all matter volatile C expressed as per cent of ordinary weight; **5**, Weight, air-dry is for wood with 12 per cent moisture; sity, see metric unit tables 76 and 77; **6-10**, 762 mm (30 in.) long specimen on 711.2 mm (28 in.) span, with center.

TABLE 78.—Mechanical Properties of Hardwoods Grown in U. S. (English Units)

Common and botanical name.	Locality where grown.	Moisture content, green, per cent.	Weight. lb/ft³		Static bending.			Impact bending.	Compression.		Shear.	Tension.
			Green.	Air-dry.	P-limit, lb/in²	Modulus of rupture, lb/in²	Modulus of elasticity 1000 × lb/in²	P-limit, lb/in²	Parallel to grain. P-limit. lb/in²	Perpendicular to grain, P-limit lb/in²	Parallel to grain, ult. st. lb/in²	Perpendicular to grain, ult. st. lb/in²
1	2	3	4	5	6	7	8	9	11	13	14	15
Alder, red (*Alnus oregona*)	Wash.	98	46	28	3800	6500	1170	8000	2650	310	770	390
Ash, black (*Fraxinus nigra*)	Mich. and Wis.	83	53	34	2600	6000	1020	7200	1620	430	870	490
Ash, white (forest grown) (*Fraxinus americana*)	Ark. and W. Va.	43	46	40	4900	9100	1350	11700	3230	800	1260	620
Ash, white (2d growth) (*Fraxinus americana*)	N. Y.	40	51	46	6100	10800	1640	13800	3820	790	1600	790
Aspen (*Populus tremuloides*)	Wis.	107	47	27	2900	5300	840	6900	1620	200	620	180
Basswood (*Tilia americana*)	Wis. and Pa.	103	41	26	2700	5000	1030	6200	1710	210	610	280
Beech (*Fagus atropunicea*)	Ind. and Pa.	62	55	44	4500	8200	1240	10400	2550	610	1210	760
Birch, paper (*Betula papyrifera*)	Wis. and Pa.	72	51	38	2900	5800	1010	7800	1650	300	790	380
Birch, yellow (*Betula lutea*)	Wis.	68	58	45	4600	8600	1540	11700	2760	450	1110	480
Butternut (*Juglans cinerea*)	Tenn. and Wis.	104	46	27	2900	5400	970	7300	1960	270	760	430
Cherry, black (*Prunus serotina*)	Pa.	55	46	36	4200	8000	1310	10200	2940	440	1130	570
Chestnut (*Castanea dentata*)	Md. and Tenn.	122	55	30	3100	5600	930	7900	2040	380	800	430
Cottonwood (*Populus deltoides*)	Mo.	111	49	29	2900	5300	1010	7200	1770	240	680	410
Cucumber tree (*Magnolia acuminata*)	Tenn.	80	50	33	4200	7400	1560	9300	2760	410	990	440
Dogwood (flowering) (*Cornus florida*)	Tenn.	62	65	54	4800	8800	1180	7100	—	1030	1520	—
Elm, cork (*Ulmus racemosa*)	Wis.	50	54	45	4600	9500	1190	11000	2870	750	1270	660
Elm, white (*Ulmus americana*)	Wis. and Pa.	88	52	35	3600	6900	1030	8100	2290	390	920	560
Gum, blue (*Eucalyptus globulus*)	Cal.	79	70	54	7600	11200	2010	14200	4870	1020	1550	640
Gum, cotton (*Nyssa aquatica*)	La.	97	56	34	4200	7300	1050	9000	2760	590	1190	600
Gum, red (*Liquidambar styraciflua*)	Mo.	81	50	36	3700	6800	1150	10000	2360	460	1070	510
Hickory, pecan (*Hicoria pecan*)	Mo.	63	61	46	5200	9800	1370	12300	3040	960	1480	680
Hickory, shagbark (*Hicoria ovata*)	O., Miss., Pa. and W. Va.	60	64	51	5900	11000	1570	14400	3430	1000	1320	—
Holly, American (*Ilex opaca*)	Tenn.	82	57	40	3400	6500	900	8900	1970	610	1130	610
Laurel, mountain (*Kalmia latifolia*)	Tenn.	62	62	49	5800	8400	920	10200	—	1110	1670	—
Locust, black (*Robinia pseudacacia*)	Tenn.	40	58	49	8800	13800	1850	18300	6280	1430	1760	770
Locust, honey (*Gleditsia triacanthos*)	Mo. and Ind.	63	61	47	5600	10200	1290	11800	3320	1420	1660	930
Magnolia (evergreen) (*Magnolia foetida*)	La.	117	62	35	3600	6800	1110	8800	2200	570	1040	610
Maple, silver (*Acer saccharinum*)	Wis.	66	46	34	3100	5800	940	6800	1950	460	1050	560
Maple, sugar (*Acer saccharum*)	Ind., Pa. and Wis.	60	56	44	5000	9100	1480	12100	3120	750	1380	770
Oak, canyon live (*Quercus chrysolepsis*)	Cal.	62	71	56	6300	10600	1340	11200	4050	1480	1700	970
Oak, red (*Quercus rubra*)	Ark., La., Ind. and Tenn.	84	64	45	3700	7700	1290	10400	2330	730	1120	740
Oak, white (*Quercus alba*)	Ark., La. and Ind.	68	62	47	4700	8300	1250	10700	2990	830	1250	770
Persimmon (*Diospyros virginiana*)	Mo.	58	63	53	5600	10000	1370	12100	3030	1110	1470	770
Poplar, yellow (*Liriodendron tulipifera*)	Tenn.	64	38	28	3200	5600	1210	8000	2000	310	790	460
Sycamore (*Platanus occidentalis*)	Ind. and Tenn.	83	52	35	3300	6500	1060	8800	2390	450	1000	630
Walnut, black (*Juglans nigra*)	Ky.	81	58	39	5400	9500	1420	11900	3600	600	1220	570

NOTE. — Results of tests on sixty-eight species; test specimens, small clear pieces, 2 by 2 inches in section, 30 inches long for bending; others, shorter. Tested in a green condition. Data taken from Bulletin 556, Forest Service, U. S. Dept. of Agriculture, containing data on 130,000 tests. See pages 133 and 135 for explanation of columns.

Common and botanical name.	Locality where grown.	Moisture content, green, per cent.	Weight. Green. lb/ft³	Weight. Air-dry. lb/ft³	Static bending. P-limit, lb/in²	Static bending. Modulus of rupture, lb/in²	Static bending. Modulus of elasticity 1000 × lb/in²	Impact bending. P-limit, lb/in²	Compression. Parallel to grain. P-limit. lb/in²	Compression. Perpendicular to grain, P-limit lb/in²	Shear. Parallel to grain, ult. st. lb/in²	Tension. Perpendicular to grain, ult. st. lb/in²
1	2	3	4	5	6	7	8	9	11	13	14	15
Cedar, incense.......... (*Libocedrus decurrens*)	Cal. and Ore.	108	45	24	3900	6200	840	7300	2870	460	830	280
Cedar, Port Orford...... (*Chamaecyparis lawsoniana*)	Ore.	52	39	31	3900	6800	1500	9300	3970	380	880	240
Cedar, western red...... (*Thuja plicata*)	Wash. and Mont.	39	27	23	3300	5200	950	7100	2500	310	720	210
Cedar, white.......... (*Thuja occidentalis*)	Wis.	55	28	21	2600	4200	640	5300	1420	290	620	240
Cypress, bald.......... (*Taxodium distichum*)	La. and Mo.	87	48	30	4000	6800	1190	8000	3100	470	820	280
Fir, amabilis........... (*Abies amabilis*)	Ore. and Wash.	102	47	27	3900	6300	1300	7800	2380	320	670	240
Fir, balsam............ (*Abies balsamea*)	Wis.	117	45	25	3000	4900	960	6900	2220	210	610	180
Fir, Douglas (1)........ (*Pseudotsuga taxifolia*)	Wash. and Ore.	36	38	34	5000	7800	1580	9400	3400	530	910	200
Fir, Douglas (2)........ (*Pseudotsuga taxifolia*)	Mont. and Wyo.	38	34	32	3600	6400	1180	9100	2520	450	880	350
Fir, grand............. (*Abies grandis*)	Mont. and Ore.	94	44	27	3600	6100	1300	8100	2680	340	700	230
Fir, noble............. (*Abies nobilis*)	Ore.	41	31	26	3400	5700	1280	7900	2370	310	700	180
Fir, white............. (*Abies concolor*)	Cal.	156	56	26	3900	6000	1130	7200	2610	440	730	260
Hemlock (eastern)...... (*Tsuga canadensia*)	Tenn. and Wis.	105	48	29	4200	6700	1120	7900	2710	500	880	260
Hemlock (western)...... (*Tsuga heterophylla*)	Wash.	71	41	29	3400	6100	1190	7800	2290	350	810	260
Larch, western......... (*Larix occidentalis*)	Mont. and Wash.	58	48	37	4600	7500	1350	9400	3250	560	920	230
Pine, Cuban........... (*Pinus heterophylla*)	Fla.	47	53	45	5600	8800	1630	11300	3950	590	1030	290
Pine, loblolly........... (*Pinus taeda*)	Fla., N. and S. Car.	70	54	39	4400	7500	1380	9500	2870	550	900	280
Pine, lodgepole......... (*Pinus contorta*)	Col., Mont. and Wyo.	65	39	28	3000	5500	1080	7200	2100	310	690	220
Pine, longleaf.......... (*Pinus palustris*)	Fla., La. and Miss.	47	50	43	5400	8700	1630	10800	3840	600	1070	290
Pine, Norway.......... (*Pinus resinosa*)	Wis.	54	42	34	3700	6400	1380	7500	2470	360	780	190
Pine, pitch............ (*Pinus rigida*)	Tenn.	85	54	35	3700	6700	1120	9100	2100	510	950	350
Pine, shortleaf.......... (*Pinus echinata*)	Ark. and La.	64	50	37	4500	8000	1450	11200	3650	480	890	330
Pine, sugar............ (*Pinus lambertiana*)	Cal.	123	50	26	3300	5300	970	6700	2340	350	710	270
Pine, western white..... (*Pinus monticola*)	Mont.	58	39	30	3500	5700	1330	7600	2770	300	710	250
Pine, western yellow.... (*Pinus ponderosa*)	Col., Mont., Ariz., Wash. and Cal.	95	46	28	3100	5200	1010	6700	2080	340	680	280
Pine, white............ (*Pinus strobus*)	Wis.	74	39	27	3400	5300	1070	6500	2370	310	640	260
Spruce, red............ (*Picea rubens*)	N. H. and Tenn.	43	34	28	3400	5700	1180	7200	2360	350	770	220
Spruce, Sitka.......... (*Picea sitchensis*)	Wash.	53	33	26	3000	5500	1180	7900	2280	330	780	230
Tamarack............. (*Larix laricina*)	Wis.	52	47	38	4200	7200	1240	7800	3010	480	860	260
Yew, western........... (*Taxus brevifolia*)	Wash.	44	54	45	6500	10100	990	13100	3400	1040	1620	450

Column Notes (*continued*). — (**7**) recommended allowable working stress (interior construction): $\frac{1}{6}$ tabular value; experimental results on tests of air-dry timber in small clear pieces average 50 per cent higher; kiln-dry, double tabular values; (**10**) repeated falls of 50-lb. hammer from increasing heights; **11–12**, 203.2-mm (8 in.) long specimen loaded on ends with deformations measured in a 152.4-mm (6 in.) gage length; (**12**) allowable working stress $\frac{1}{3}$ tabular crushing strength; (**13**) 152.4-mm (6 in.) long block loaded on its side with a central bearing area of 2580.6-mm² (4 in²) allowable working stress, $\frac{2}{3}$ tabular value. (**14**) 50.8-mm by 50.8-mm (2 in.) projecting lip sheared from block; allowable working stress, $\frac{1}{8}$ tabular value; (**15**) 63.5-mm ($2\frac{1}{2}$ in.) specimen with 25.4-mm (1 in.) free loaded length; allowable working stress, $\frac{1}{8}$ tabular value. (**16–17**) for values in lbs. multiply values of metric tables by 2.2.

ELASTIC MODULI

TABLE 80.—Rigidity Modulus

If to the four consecutive faces of a cube a tangential stress is applied, opposite in direction on adjacent sides, the modulus of rigidity is obtained by dividing the numerical value of the tangential stress per unit area (kg per sq. mm) by the number representing the change of angles on the non-stressed faces, measured in radians.

Substance.	Rigidity Modulus.	Reference.	Substance.	Rigidity Modulus.	Reference.
Aluminum	3350	14	Quartz fibre	2888	20
" cast	2580	5	" "	2380	21
Brass	3550	10	Silver	2960	5
"	3715	11	"	2650	10
" cast, 60 Cu + 12 Sn	3700	5	"	2566	16
Bismuth, slowly cooled	1240	5	" hard-drawn	2816	11
Bronze, cast, 88 Cu + 12 Sn	4060	5	Steel	8290	16
Cadmium, cast	2450	5	" cast	7458	15
Copper, cast	4780	5	" cast, coarse gr.	8070	5
"	4213	18	" silver-	7872	11
"	4450	10	Tin, cast	1730	5
"	4664	19	"	1543	19
Gold	2850	5	Zinc	3880	5
"	3950	14	"	3820	19
Iron, cast	5210	5	Platinum	6630	16
"	6706	15	"	6220	22
"	7975	10	Glass	2350	–
"	6940	7	"	2730	–
"	8108	16	Clay rock	1770	23
"	7505	14	Granite	1280	23
Magnesium, cast	1710	5	Marble	1190	23
Nickel	7820	5	Slate	2290	23
Phosphor bronze	4359	11			

References 1–16, see Table 48.
17 Grätz, Wied. Ann. 28, 1886.
18 Savart, Pogg. Ann. 16, 1829.
19 Kiewiet, Diss. Göttingen, 1886.
20 Threlfall, Philos. Mag. (5) 30, 1890.
21 Boys, Philos. Mag. (5) 30, 1890.
22 Thomson, Lord Kelvin.
23 Gray and Milne.
24 Adams-Coker, Carnegie Publ. No. 46, 1906.

TABLE 81.—Variation of the Rigidity Modulus with the Temperature

$n_t = n_o(1 - \alpha t - \beta t^2 - \gamma t^3)$, where t = temperature Centigrade.

Substance.	n_o	$\alpha 10^6$	$\beta 10^8$	$\gamma 10^{10}$	Authority.
Brass	2652	2158	48	32	Pisati, Nuovo Cimento, 5, 34, 1879.
"	3200	455	36	–	Kohlrausch-Loomis, Pogg. Ann. 141.
Copper	3972	2716	−23	47	Pisati, loc. cit.
"	3900	572	28	–	K and L, loc. cit.
Iron	8108	206	19	−11	Pisati, loc. cit.
"	6940	483	12	–	K and L, loc. cit.
Platinum	6632	111	50	−8	Pisati, loc. cit.
Silver	2566	387	38	11	" " "
Steel	8290	187	59	−9	" " "

$n_t{}^* = n_{15}[1 - \alpha(t - 15)]$; Horton, Philos. Trans. 204 A, 1905.

Copper	4.37*	α = .00039	Platinum	6.46*	α = .00012	Tin	1.50*	α = .00416
Copper (commercial)	3.80	.00038	Gold	2.45	.00031	Lead	0.80	.00164
Iron	8.26	.00029	Silver	2.67	.00048	Cadmium	2.31	.0058
Steel	8.45	.00026	Aluminum	2.55	.00148	Quartz	3.00	.00012

* Modulus of rigidity in 10^{11} dynes per sq. cm

TABLE 82.—Interior Friction at Low Temperatures

C is the damping coefficient for infinitely small oscillations; T, the period of oscillation in seconds; N, the second modulus of elasticity. Guye and Schapper, C. R. 150, p. 963, 1910.

		Substance	Cu	Ni	Au	Pd	Pt	Ag	Quartz
		Length of wire in cm.	22.5	22.2	22.3	22.2	23.0	17.2	17.3
		Diameter in mm.	.643	.411	.609	.553	.812	.601	.612
100° C	C		24.1	1.34	27.5	1.67	2.98	55.8	—
	T		2.381s	3.831s	3.010s	2.579	1.143s	1.808s	—
	$N \times 10^{-11}$		3.32	7.54	2.55	5.08	5.77	2.71	—
0° C	C		5.88	.417	4.82	1.25	4.60	7.19	4.69
	T		2.336s	3.754s	2.969s	2.571s	1.133s	1.759s	1.408s
	$N \times 10^{-11}$		3.45	7.85	2.62	5.12	—	2.87	2.26
−195° C	C		3.64	.556	6.36	.744	3.02	1.64	1.02
	T		2.274s	3.577s	2.902s	2.552s	1.111s	1.694s	1.425s
	$N \times 10^{-11}$		3.64	8.65	2.74	5.19	6.10	3.18	2.20

TABLE 83.—Hardness

Agate	7.	Brass	3–4.	Iridosmium	7.	Sulphur	1.5–2.5
Alabaster	1.7	Calamine	5.	Iron	4–5.	Stibnite	2.
Alum	2–2.5	Calcite	3.	Kaolin	1.	Serpentine	3–4.
Aluminum	2.	Copper	2.5–3.	Loess (0°)	0.3	Silver	2.5–3.
Amber	2–2.5	Corundum	9.	Magnetite	6.	Steel	5–8.5
Andalusite	7.5	Diamond	10.	Marble	3–4.	Talc	1.
Anthracite	2.2	Dolomite	3.5–4.	Meerschaum	2–3.	Tin	1.5
Antimony	3.3	Feldspar	6.	Mica	2.8	Topaz	8.
Apatite	5.	Flint	7.	Opal	4–6.	Tourmaline	7.3
Aragonite	3.5	Fluorite	4.	Orthoclase	6.	Wax (0°)	0.2
Arsenic	3.5	Galena	2.5	Palladium	4.8	Wood's metal	3.
Asbestos	5.	Garnet	7.	Phosphorbronze	4.		
Asphalt	1–2.	Glass	4.5–6.5	Platinum	4.3		
Augite	6.	Gold	2.5–3.	Platin-iridium	6.5		
Barite	3.3	Graphite	0.5–1.	Pyrite	6.3		
Beryl	7.8	Gypsum	1.6–2.	Quartz	7.		
Bell-metal	4.	Hematite	6.	Rock-salt	2.		
Bismuth	2.5	Hornblende	5.5	Ross' metal	2.5–3.0		
Boric acid	3.	Iridium	6.	Silver chloride	1.3		

From Landolt-Börnstein-Meyerhoffer Tables: Auerbachs, Winklemann, Handb. der Phys. 1891.

TABLE 84.—Relative Hardness of the Elements (Means)

C	10.	Ir	6.5	Pt	4.3	Al	2.9	Se	2.0	In	1.2
B	9.5	Ge	6.2	Ti	4.0	Ag	2.7	Cd	2.0	Tl	1.2
Cr	9.	Rh	6.	Pd	4.0	Zn	2.5	Sr	1.8	Li	0.6
Ru	7.5	Mo	6?	Fe	4.	Te	2.3	Bi	1.8	K	0.5
Ta	7.	Mn	6.	As	3.5	Mg	2.6	Sn	1.8	Na	0.4
Os	7.	Co	5.	Sb	3.	Au	2.5	Pb	1.5	Rb	0.3
W	7.	Ni	5.	Be	3.	Ce	2.5	Ga	1.5	Cs	0.2
Si	6.5	Zr	4.5	Cu	3.0	S	2.0	Hg	1.5		

TABLE 85.—Ratio, ρ, of Transverse Contraction to Longitudinal Extension under Tensile Stress

(Poisson's Ratio)

Metal	Pb	Au	Pd	Pt	Ag	Cu	Al	Bi	Sn	Ni	Cd	Fe
ρ	0.45	0.42	0.39	0.39	0.38	0.35	0.34	0.33	0.33	0.31	0.30	0.28

From data from Physikalisch-Technischen Reichsanstalt, 1907.

ρ for: marbles, 0.27; granites, 0.24; basic-intrusives, 0.26; glass, 0.23. Adams-Coker, 1906.

TABLE 86

ELASTICITY OF CRYSTALS *

The formulæ were deduced from experiments made on rectangular prismatic bars cut from the crystal. These bars were subjected to cross bending and twisting and the corresponoing Elastic Moduli deduced. The symbols $\alpha\ \beta\ \gamma$, $\alpha_1\ \beta_1\ \gamma_1$ and $\alpha_2\ \beta_2\ \gamma_2$ represent the direction cosines of the length, the greater and the less transverse dimensions of the prism with reference to the principal axis of the crystal. E is the modulus for extension or compression, and T is the modulus for torsional rigidity. The moduli are in grams per square centimeter.

Barite.

$$\frac{10^{10}}{E} = 16.13\alpha^4 + 18.51\beta^4 + 10.42\gamma^4 + 2(38.79\beta^2\gamma^2 + 15.21\gamma^2\alpha^2 + 8.88\alpha^2\beta^2)$$

$$\frac{10^{10}}{T} = 69.52\alpha^4 + 117.66\beta^4 + 116.46\gamma^4 + 2(20.16\beta^2\gamma^2 + 85.29\gamma^2\alpha^2 + 127.35\alpha^2\beta^2)$$

Beryl (Emerald).

$$\frac{10^{10}}{E} = 4.325 \sin^4\phi + 4.619 \cos^4\phi + 13.328 \sin^2\phi \cos^2\phi$$

$$\frac{10^{10}}{T} = 15.00 - 3.675 \cos^4\phi_2 - 17.536 \cos^2\phi \cos^2\phi_1$$

where $\phi\ \phi_1\ \phi_2$ are the angles which the length, breadth, and thickness of the specimen make with the principal axis of the crystal.

Fluorite.

$$\frac{10^{10}}{E} = 13.05 - 6.26 (\alpha^4 + \beta^4 + \gamma^4)$$

$$\frac{10^{10}}{T} = 58.04 - 50.08 (\beta^2\gamma^2 + \gamma^2\alpha^2 + \alpha^2\beta^2)$$

Pyrite.

$$\frac{10^{10}}{E} = 5.08 - 2.24 (\alpha^4 + \beta^4 + \gamma^4)$$

$$\frac{10^{10}}{T} = 18.60 - 17.95 (\beta^2\gamma^2 + \gamma^2\alpha^2 + \alpha^2\beta^2)$$

Rock salt.

$$\frac{10^{10}}{E} = 33.48 - 9.66 (\alpha^4 + \beta^4 + \gamma^4)$$

$$\frac{10^{10}}{T} = 154.58 - 77.28 (\beta^2\gamma^2 + \gamma^2\alpha^2 + \alpha^2\beta^2)$$

Sylvite.

$$\frac{10^{10}}{E} = 75.1 - 48.2 (\alpha^4 + \beta^4 + \gamma^4)$$

$$\frac{10^{10}}{T} = 306.0 - 192.8 (\beta^2\gamma^2 + \gamma^2\alpha^2 + \alpha^2\beta^2)$$

Topaz.

$$\frac{10^{10}}{E} = 4.341\alpha^4 + 3.460\beta^4 + 3.771\gamma^4 + 2 (3.879\beta^2\gamma^2 + 2.856\gamma^2\alpha^2 + 2.39\alpha^2\beta^2)$$

$$\frac{10^{10}}{T} = 14.88\alpha^4 + 16.54\beta^4 + 16.45\gamma^4 + 30.89\beta^2\gamma^2 + 40.89\gamma^2\alpha^2 + 43.51\alpha^2\beta^2$$

Quartz.

$$\frac{10^{10}}{E} = 12.734 (1 - \gamma^2)^2 + 16.693 (1 - \gamma^2)\gamma^2 + 9.705\gamma^4 - 8.460\beta\gamma (3\alpha^2 - \beta^2)$$

$$\frac{10^{10}}{T} = 19.665 + 9.060\gamma_2^2 + 22.984\gamma^2\gamma_1^2 - 16.920 [(\gamma\beta_1 + \beta\gamma_1) (3\alpha\alpha_1 - \beta\beta_1) - \beta_2\gamma_2)]$$

* These formulæ are taken from Voigt's papers (Wied. Ann. vols. 31, 34, and 35).

TABLE 87

ELASTICITY OF CRYSTALS

Some particular values of the Elastic Moduli are here given. Under E are given moduli for extension or compression in the directions indicated by the subscripts and explained in the notes, and under T the moduli for torsional rigidities round the axes similarly indicated. Moduli in grams per sq. cm.

(a) ISOMETRIC SYSTEM *

Substance.	E_a	E_b	E_c	T_a	Authority.
Fluorite	1473×10^6	1008×10^6	910×10^6	345×10^6	Voigt.†
Pyrite	3530×10^6	2530×10^6	2310×10^6	1075×10^6	"
Rock salt	419×10^6	349×10^6	303×10^6	129×10^6	"
"	403×10^6	339×10^6	—	—	Koch.‡
Sylvite	401×10^6	209×10^6	—	—	"
"	372×10^6	196×10^6	—	655×10^5	Voigt.
Sodium chlorate	405×10^6	319×10^6	—	—	Koch.
Potassium alum	181×10^6	199×10^6	—	—	Beckenkamp.§
Chromium alum	161×10^6	177×10^6	—	—	"
Iron alum	186×10^6	—	—	—	"

(b) ORTHORHOMBIC SYSTEM ||

Substance.	E_1	E_2	E_3	E_4	E_5	E_6	Authority.
Barite	620×10^6	540×10^6	959×10^6	376×10^6	702×10^6	740×10^6	Voigt.
Topaz	2304×10^6	2890×10^6	2652×10^6	2670×10^6	2893×10^6	3180×10^6	"

Substance.	$T_{12} = T_{21}$	$T_{13} = T_{31}$	$T_{23} = T_{32}$	Authority.
Barite	283×10^6	293×10^6	121×10^6	Voigt.
Topaz	1336×10^6	1353×10^6	1104×10^6	"

In the MONOCLINIC SYSTEM, Coromilas (Zeit. für Kryst. vol. 1) gives

Gypsum $\begin{cases} E_{max} = 887 \times 10^6 \text{ at } 21.9^\circ \text{ to the principal axis.} \\ E_{min} = 313 \times 10^6 \text{ at } 75.4^\circ \text{ " " "} \end{cases}$

Mica $\begin{cases} E_{max} = 2213 \times 10^6 \text{ in the principal axis.} \\ E_{min} = 1554 \times 10^6 \text{ at } 45^\circ \text{ to the principal axis.} \end{cases}$

In the HEXAGONAL SYSTEM, Voigt gives measurements on a beryl crystal (emerald). The subscripts indicate inclination in degrees of the axis of stress to the principal axis of the crystal.

$E_0 = 2165 \times 10^6$, $E_{45} = 1796 \times 10^6$, $E_{90} = 2312 \times 10^6$,
$T_0 = 667 \times 10^6$, $T_{90} = 883 \times 10^6$. The smallest cross dimension of the prism experimented on (see Table 86), was in the principal axis for this last case.

In the RHOMBOHEDRAL SYSTEM, Voigt has measured quartz. The subscripts have the same meaning as in the hexagonal system.

$E_0 = 1030 \times 10^6$, $E_{-45} = 1305 \times 10^6$, $E_{+45} = 850 \times 10^6$, $E_{90} = 785 \times 10^6$,
$T_0 = 508 \times 10^6$, $T_{90} = 348 \times 10^6$.

Baumgarten ¶ gives for calcite

$E_0 = 501 \times 10^6$, $E_{-45} = 441 \times 10^6$, $E_{+45} = 772 \times 10^6$, $E_{90} = 790 \times 10^6$.

* In this system the subscript *a* indicates that compression or extension takes place along the crystalline axis, and distortion round the axis. The subscripts *b* and *c* correspond to directions equally inclined to two and normal to the third and equally inclined to all three axes respectively.
† Voigt, "Wied. Ann." 31, p. 474, p. 701, 1887; 34, p. 981, 1888; 36, p. 642, 1888
‡ Koch, "Wied. Ann." 18, p. 325, 1882.
§ Beckenkamp, "Zeit. für Kryst." vol. 10.
|| The subscripts 1, 2, 3 indicate that the three principal axes are the axes of stress; 4, 5, 6 that the axes of stress are in the three principal planes at angles of 45° to the corresponding axes.
¶ Baumgarten, "Pogg. Ann." 152, p. 369, 1879.

MECHANICAL PROPERTIES OF SOME SINGLE METAL CRYSTALS (BRIDGMAN)

All the following metals have an axis of rotational symmetry: Zn and Cd have a 6-fold axis (hexagonal system); Bi, Sb, Te, 3-fold, trigonal; Sn, 4-fold, tetragonal. The rotational axis is taken as the datum line. The notation of Voigt is used (Lehrbuch der Kristallphysik, Berlin, 1910). Bridgman, Proc. Amer. Acad. Arts and Sci., 60, 305, 1925.

TABLE 88.—Elastic Constants, Abs. c.g.s. units

Constant	Zn	Cd	Bi	Sb	Te	Sn	W
s_{11}	8.23×10^{-13}	12.9×10^{-13}	26.9×10^{-13}	17.7×10^{-13}	48.7×10^{-13}	18.5×10^{-13}	2.534×10^{-13}
s_{12}	+0.34	−1.5	−14.0	−3.8	−6.9	−9.9	−0.726
s_{13}	−6.64	−9.3	−6.2	−8.5	−13.8	−2.5	s_{12}
s_{33}	26.38	36.9	28.7	33.8	23.4	11.8	s_{11}
s_{44}	25.0	64.0	104.8	41.0	58.1	57.0	6.55
$\frac{1}{2}s_{66}$	$s_{11}-s_{12}$	$s_{11}-s_{12}$	$s_{11}-s_{12}$	$s_{11}-s_{12}$	$s_{11}-s_{12}$	67.5	$s_{11}-s_{12}$
s_{14}	0	0	+16	−8.0	—	0	0

TABLE 89.—Linear Compressibility, l/l_0

Pressure in kg/cm² Range 12,000 kg/cm²

Metal	at 30° C		at 75° C	
Zn	$12.98 \times 10^{-7}p$	$-5.32 \times 10^{-12}p^2$	$13.55 \times 10^{-7}p$	$-7.82 \times 10^{-12}p^2$
	1.946	−1.11	2.025	−1.47
Bi	15.92	−11.1	15.80	−11.6
	6.450	−4.60	6.423	−4.57
Sb	16.48	−20.5	16.37	−18.0
	5.256	−4.56	5.091	−3.04
Te	−4.137	+9.6	−5.132	+13.2
	27.48	−52.7	27.77	−53.6
Sn	6.719	−4.07	6.956	−3.91
	6.022	−4.20	6.144	−4.26

TABLE 90.—Cubic Compressibility

(V/V_0); Pressure kg/cm² Range, 12,000 kg/cm² (calculated)

Metal	at 30° C		at 75° C	
Zn	$16.87 \times 10^{-7}p$	$-8.08 \times 10^{-12}p^2$	$17.60 \times 10^{-7}p$	$-11.35 \times 10^{-12}p^2$
Bi	29.17	−22.43	29.89	−31.13
Sb	26.99	−31.6	26.55	−25.3
Te	50.82	−101.1	50.41	−85.6
Sn	18.76	−13.6	19.24	−13.7
W	3.18	−1.4	3.18	−1.5

CALCULATIONS INVOLVING THE RELATIONS BETWEEN THE TEMPERATURES, PRESSURES, VOLUMES, AND WEIGHTS OF GASES

(Abridged from S. F. Pickering, Bur. Standards Circ. 279, which see for further details.)

Simple laws.—Any amount of gas completely fills the space in which it is confined. The pressure it exerts upon the confining walls depends upon the temperature. A quantity of gas can not be specified by volume only; all three factors—volume, temperature, and pressure—must be stated. The relations between these three factors are expressed by means of the following equation,

$$pv = KT \tag{1}$$

in which p, v, and T represent simultaneous values of the pressure, volume, and absolute temperature of any definite quantity of gas, while K is a constant, the numerical value of which depends upon the quantity of gas considered and the units in which pressure, volume, and temperature are measured.

While the behavior of gases at atmospheric pressure closely approximates the equation (1), the relation is not exact. The expansion of air is nearer one 272nd of its volume at 273.1° K. per degree. For most practical purposes such errors may be neglected.

If we take weights of gases proportional to their molecular weights, a new relation of the greatest importance develops: *The value of the constant in equation (1) is the same for each gas.* It is customary to use as the unit of quantity, the mol, the number of grams of gas equal to the molecular weight. When 1 mol is the quantity considered, the resulting value of K is designated R.

Absolute temperature	Pressure	Volume	R
°C + 273.1	Atmosphere	Liter	0.08206
°C + 273.1	mm of mercury	do	62.37
°C + 273.1	Gram per cm²	do	84.79
°C + 273.1	Megabar	do	.08315
°C + 273.1	Atmosphere	Cubic feet	.002898
°C + 273.1	mm of mercury	do	2.2024
°C + 273.1	Inches of mercury	do	.08671
°C + 273.1	Pounds per in.²	do	.04259

With the mol the unit of quantity, N the number of mols of gas, equation (1) becomes

$$pv = NRT \tag{2}$$

By the use of equation (2), the above table, and a table of molecular weights, the solution of any problem involving volumes, temperatures, pressures, and weights of gases is very simple.

Mixtures of gases.—Any quantity of gas fills the space in which it is confined and exerts a pressure upon the confining walls. If an additional quantity is added, the pressure is increased in direct proportion to the quantity added. One can regard the pressure exerted by each portion of the total quantity of gas as independent of the presence of the rest. This is true if the second portion of gas is different chemically from the first (Dalton's law), provided the gases do not react chemically.

Vapor pressure and the effect of vapor pressure upon the measurement of gas.—If a volatile liquid is introduced, a portion evaporates and exerts a pressure on the confining walls. The amount evaporated and the pressure exerted are independent of the presence of any other gas. If there is enough so that not all evaporates and if time is allowed for equilibrium, the pressure is independent of the volume of space and of the amount of liquid left unevaporated; but it does depend upon the temperature. For each volatile liquid there is therefore a definite saturation pressure or vapor pressure corresponding to every temperature (see pages 223 to 232).

When any gas is in contact with a volatile substance, the measured pressure is the pressure exerted by the gas plus the vapor pressure of the volatile material. With no change of temperature, this vapor pressure remains constant no matter how we change the total pressure. Hence for the purposes of volume conversion the saturated gas may be considered as a dry gas, the pressure of which is the partial pressure of the gas, or its equivalent, the difference between the total pressure and the saturated vapor pressure of the volatile material.

Volume conversions involving high pressures.—In the measurement of gases at high pressures, pressure 2,000 lbs./in.², the quantity pv is no longer constant at constant temperature, but varies with the pressure by amounts which differ for each gas. Consequently the relation $p_1v_1/T_1 = p_2v_2/T_2$ is no longer true.

In Table 92 $\{273.1/T\}pv$ is given as a function of the pressure. This quantity $\{273.1/T\}pv$ is called the factor (F). Consider the 0°C isothermals. They are taken on the basis of pv at 0°C and 1 atm. as unity. The factor for any pressure given by the table will represent the ratio of the value of pv at this pressure to the value of pv at 1 atmosphere; that is,

$$(pv)_n/(pv)_1 = F_n$$

where F_n is the factor for n atmospheres. This relation, of course, holds for all pressures, therefore, $v_m = v_n\{P_nF_m/P_mF_n\}$. The corrections are made as though the substance behaved as a perfect gas, and the result multiplied by the ratio of the factor at the desired pressure to the factor at the measured pressure.

TABLE 92.—Values of Factor

$F = (273.1/T)_{pv}$. (See p. 141)

$v = 1$ at 1 atm. pressure, 0° C

Atm.	Air: Holborn, Schultze, 1915				Argon: Holborn, Schultze, 1915				Neon*
	0°C	50°C	100°C	200°C	0°C	50°C	100°C	200°C	0°C
10	.9950	.9995	1.0019	1.0059	.9919	.9971	.9998	1.0021	1.0043
25	.9875	.9985	1.0042	1.0082	.9782	.9916	.9982	1.0042	1.0117
50	.9780	.9994	1.0098	1.0175	.9575	.9840	.9969	1.0082	1.0233
75	.9720	1.002	1.0189	1.0275	.9401	.9781	.9969	1.0136	1.0356
100	.9710	1.0075	1.0251	1.0380	.9260	.9744	.9988	1.0195	(1.0490)

Atm.	Helium: Holborn, Otto, 1922			Hydrogen: Holborn, 1920			Oxygen: Holborn, Otto, 1922			
	0°C	50°C	100°C	0°C	50°C		0°C	20°C	50°C	100°C
10	1.0048	1.0040	1.0033	1.0055	1.0055	1.0045	.9915	.9940	.9972	1.0000
25	1.0127	1.0106	1.0090	1.0150	1.0136	1.0122	.9778	.9842	.9915	.9987
50	1.0258	1.0216	1.0183	1.0311	1.0280	1.0248	.9569	.9692	.9838	.9975
75	1.0390	1.0327	1.0277	1.0475	1.0422	1.0375	.9385	....	.9778	.9978
100	1.0522	1.0438	1.0370	1.0640	1.0565	1.0500	.9238	....	.9740	.9990

Atm.	Nitrogen Mean †			Methane: Keyes, Smith, Joubert			
	0°C	50°C	100°C	0°C	50°C	100°C	200°C
10	.996	1.000	1.002	.978	.989	.993	.999
50	.982	1.002	1.011	.883	.941	.971	.997
100	.982	1.013	1.028	.781	.896	.951	.998
150	1.000	1.037	1.053	(.730)	.873	.943	1.004
200	....	1.067	1.082	...	.873	.950	1.020

*Onnes, Crommelin, 1915.
† Holborn, Otto, 1922, Smith, Taylor, 1923.

TABLE 93.—Relative Gas Volumes at Various Pressures

(Deduced by Cochrane, from the *pv* curves of Amagat and other observers)

Relative volumes when the pressure is reduced from the value given at the head of the column to 1 atmosphere; see also Bur. Standards Circ. 279:

Gas (Temp. = 16°C)	Relative volume which the gas will occupy when the pressure is reduced to atmospheric from					
	1 atm.	50 atm.	100 atm.	120 atm.	150 atm.	200 atm.
"Perfect" gas	1	50	100	120	150	200
Helium	1	...	94.6	112.5	141	....
Hydrogen	1	48.5	93.6	111.3	136.3	176.4
Nitrogen	1	50.5	100.6	120.0	147.6	190.8
Air	1	50.9	101.8	121.9	150.3	194.8
Argon	..	...	106.3	127.6	161	....
Oxygen	1	...	105.2	....	....	212.6
Oxygen (at 0°C)	1	52.3	107.9	128.6	161.9	218.8
Carbon dioxide	1	69	477*	485*	498*	515*

* Carbon dioxide is liquid at pressures greater than 90 atmospheres.

TABLE 94

CORRECTING FACTORS: SATURATED GAS VOLUME TO VOLUME AT 760 MM HG AND 0°C

[Multiply observed volumes of saturated gas by factor to correct to volume of dry gas at 760 mm of mercury pressure (0°C) and 0°C]

(Abridged from Bur. Standards Circ. 279)

Temperature (°C)	Pressure mm of Hg. 715	720	725	730	735	740	745	750	755	760	765	770
5°	0.916	0.922	0.928	0.935	0.942	0.948	0.954	0.961	0.967	0.974	0.980	0.986
6	.912	.918	.924	.931	.937	.944	.950	.957	.963	.970	.976	.982
7	.908	.914	.920	.927	.933	.940	.946	.952	.959	.965	.972	.978
8	.904	.910	.916	.923	.929	.936	.942	.948	.955	.961	.967	.974
9	.900	.906	.912	.919	.925	.932	.938	.944	.951	.957	.963	.970
10	.896	.902	.908	.915	.921	.928	.934	.940	.946	.953	.959	.966
11	.892	.898	.904	.911	.917	.924	.920	.936	.942	.949	.955	.962
12	.888	.894	.900	.907	.913	.919	.925	.932	.939	.945	.951	.957
13	.884	.890	.896	.903	.909	.915	.921	.928	.934	.940	.947	.953
14	.880	.886	.892	.899	.905	.911	.917	.924	.930	.936	.942	.949
15	.876	.882	.888	.895	.901	.907	.913	.920	.925	.932	.938	.944
16	.872	.878	.884	.890	.896	.903	.909	.915	.921	.928	.934	.940
17	.868	.874	.880	.886	.892	.898	.905	.911	.917	.923	.929	.936
18	.864	.870	.875	.882	.888	.894	.900	.907	.913	.919	.925	.931
19	.859	.865	.871	.878	.884	.890	.896	.902	.908	.915	.920	.927
20	.855	.861	.867	.874	.879	.886	.892	.898	.904	.910	.916	.922
21	.851	.857	.863	.869	.875	.881	.887	.893	.899	.906	.912	.918
22	.847	.853	.858	.865	.871	.877	.883	.888	.894	.901	.907	.913
23	.842	.848	.854	.860	.866	.872	.878	.884	.890	.897	.903	.909
24	.838	.844	.849	.856	.862	.868	.874	.880	.886	.892	.898	.904
25	.833	.839	.845	.851	.857	.863	.869	.875	.881	.888	.893	.899
26	.829	.835	.841	.847	.853	.859	.865	.871	.877	.883	.889	.895
27	.824	.830	.836	.842	.848	.854	.860	.866	.872	.878	.884	.890
28	.820	.825	.831	.837	.843	.849	.855	.861	.867	.873	.879	.885
29	.815	.821	.826	.832	.838	.844	.850	.856	.862	.868	.874	.880
30	.810	.816	.822	.828	.833	.840	.845	.851	.857	.863	.869	.875
31	.805	.811	.817	.823	.829	.835	.840	.846	.852	.858	.864	.870
32	.800	.806	.812	.818	.823	.830	.835	.841	.847	.853	.859	.865
33	.795	.801	.807	.813	.818	.824	.830	.836	.842	.848	.853	.860
34	.790	.796	.801	.807	.813	.819	.825	.831	.837	.842	.848	.854
35	.785	.790	.796	.802	.808	.814	.819	.825	.831	.837	.843	.849
36	.780	.785	.791	.797	.802	.808	.814	.820	.826	.832	.836	.843
37	.774	.780	.785	.791	.797	.803	.809	.814	.820	.826	.832	.838
38	.769	.774	.780	.786	.791	.796	.803	.809	.814	.820	.826	.832
39	.763	.768	.774	.780	.785	.790	.797	.803	.809	.814	.820	.826
40	.756	.763	.768	.774	.780	.786	.792	.797	.803	.809	.814	.820
41	.751	.757	.762	.768	.774	.780	.786	.791	.797	.803	.808	.814
42	.745	.751	.756	.762	.768	.774	.779	.785	.791	.796	.802	.808
43	.739	.745	.750	.756	.762	.767	.773	.779	.784	.790	.796	.802
44	.733	.738	.744	.750	.755	.761	.766	.772	.778	.784	.789	.795
45	.726	.732	.737	.743	.749	.754	.760	.766	.771	.777	.783	.788
46	.720	.725	.731	.737	.742	.748	.754	.759	.765	.770	.776	.782
47	.713	.719	.724	.730	.735	.741	.746	.752	.758	.764	.769	.775
48	.706	.712	.717	.723	.728	.734	.739	.745	.751	.756	.762	.768
49	.700	.705	.710	.716	.721	.727	.732	.738	.744	.750	.755	.761

TABLES 95 AND 96

COMPRESSIBILITY OF GASES

TABLE 95.—Compressibility at Ordinary Temperatures

As a measure of the compressibility, it is customary to use a coefficient, $1 + \lambda = p_0v_0/p_1v_1$, p_0, v_0 being at 0°C

Gas	$1 + \lambda$	±
H_2	$1 + \lambda = 0.99939$	± 0.00001
N_2	1.00044	0.00001
O_2	1.00094	0.000013
He	0.99948	0.000005
Ne	0.99951	0.000025
A	1.00099	0.000026

Wild, Philos. Mag., 12, 49, 1931

Gas	$1 + \lambda$
CO	$1 + \lambda = 1.00081$
CO_2	1.00668
N_2O	1.00747

Rayleigh, Z. Phys. Chem., 52, 705, 1905

TABLE 96.—Compressibility at Low Temperatures

$pv = 1$ for 0°, 1 atmosphere

Table 96*a*.—Helium

t°C	p atm.	pv	Density
0.00	26.66	1.0146	26.28
"	38.95	1.0196	38.20
"	58.58	1.0294	56.91
−103.64	24.13	.6337	38.07
"	49.96	.6479	77.08
−269.69	.232	.01126	20.63
"	.353	.01041	33.92
−270.52	.0308	.00911	3.381
"	.0649	.00858	7.535

Bocke, Onnes, 1924

Table 96*b*.—Hydrogen

t°C	p atm.	pv	Density
0.00	32.313	1.0188	31.715
"	44.119	1.0266	43.284
−103.57	38.41	.6376	38.41
.58	51.49	.6433	80.04
−204.70	16.75	.2404	69.68
"	37.00	.2316	159.7
"	44.63	.2300	194.0
−257.26	.06698	.05783	1.1582
"	.13153	.057104	2.3031

Nighoff, Keesom, 1928; Onnes, Penning, 1903; Onnes, Braak, 1907

Table 96*c*.—Neon

t°C	p atm.	pv	Density
0.0	23.06	1.0089	21.87
"	30.79	1.0147	30.34
"	84.66	1.0408	81.35
−200.1	61.66	.2337	763.8
"	79.92	.2293	348.6
−217.5	49.93	.1393	358.5
"	64.97	.1269	511.8
"	79.42	.1256	632.2

Onnes, Crommelin, 1915

Table 96*d*.—Argon

t°C	p atm.	pv	Density
0.0	20.58	.9856	20.88
"	31.57	.9774	32.30
−102.51	14.86	.5813	25.57
"	45.09	.4706	95.80
"	62.24	.3939	158.01
−130.38	12.77	.4663	27.39
−159.62	11.99	.4262	28.12
−149.60	11.15	.3821	29.18

Onnes, Crommelin, 1910

Table 96*e*.—Oxygen

t°C	p atm.	pv	Density
0	20.92	.9813	21.32
"	49.79	.9573	52.01
− 80.03	21.01	.6550	32.09
"	34.18	.6213	55.02
"	61.88	.5464	13.23
−116.01	22.30	.4835	46.12
"	43.95	.3541	124.1
"	55.05	.1667	330.2

Onnes, Kuypers, 1923, 1924

Table 96*f*.—Nitrogen

t°C	p atm.	pv	Density
0	33.14	.9886	33.52
"	43.08	.9860	43.70
"	58.63	.9834	59.62
− 81.10	30.17	.6516	46.13
"	45.47	.6270	72.52
"	56.71	.6109	92.84
−146.32	22.92	.3340	68.62
"	30.14	.2656	113.48
"	36.49	.1058	344.5

Onnes, Van Urk, 1924

COMPRESSIBILITY OF GASES

TABLE 97.—O, Air, N, and H. Relative Volumes at Various Pressures and Temperatures, the volumes at 0°C and at 1 atmosphere being taken as 1 000 000

Atm.	Oxygen.			Air.			Nitrogen.			Hydrogen.		
	0°	99°.5	199°.5	0°	99°.4	200°.4	0°	99°.5	199°.6	0°	99°.3	200°.5
100	9265	-	-	9730	-	-	9910	-	-	-	-	-
200	4570	7000	9095	5050	7360	9430	5195	7445	9532	5690	7567	9420
300	3208	4843	6283	3658	5170	6622	3786	5301	6715	4030	5286	6520
400	2629	3830	4900	3036	4170	5240	3142	4265	5331	3207	4147	5075
500	2312	3244	4100	2680	3565	4422	2780	3655	4515	2713	3462	4210
600	2115	2867	3570	2450	3180	3883	2543	3258	3973	2387	3006	3627
700	1979	2610	3202	2288	2904	3502	2374	2980	3589	2149	2680	3212
800	1879	2417	2929	2168	2699	3219	2240	2775	3300	1972	2444	2900
900	1800	2268	2718	2070	2544	3000	2149	2616	3085	1832	2244	2657
1000	1735	2151	-	1992	2415	2828	2068	-	-	1720	2093	-

Amagat: C. R. 111, p. 871, 1890; Ann. chim. phys. (6) 29, pp. 68 and 505, 1893.

TABLE 98.—Ethylene

pv at 0°C and 1 atm. = 1

Atm.	0°	10°	20°	30°	40°	60°	80°	100°	137°.5	198°.5
46	-	0.562	0.684	-	-	-	-	-	-	-
48	-	0.508	-	-	-	-	-	-	-	-
50	0.176	0.420	0.629	0.731	0.814	0.954	1.077	1.192	1.374	1.652
52	-	0.240	0.598	-	-	-	-	-	-	-
54	-	0.229	0.561	-	-	-	-	-	-	-
56	-	0.227	0.524	-	-	-	-	-	-	-
100	0.310	0.331	0.360	0.403	0.471	0.668	0.847	1.005	1.247	1.580
150	0.441	0.459	0.485	0.515	0.551	0.649	0.776	0.924	1.178	1.540
200	0.565	0.585	0.610	0.638	0.669	0.744	0.838	0.946	1.174	1.537
300	0.806	0.827	0.852	0.878	0.908	0.972	1.048	1.133	1.310	1.628
500	1.256	1.280	1.308	1.337	1.367	1.431	1.500	1.578	1.721	1.985
1000	2.289	2.321	2.354	2.387	2.422	2.493	2.566	2.643	2.798	-

Amagat, C. R. 111, p. 871, 1890; 116, p. 946, 1893.

TABLE 99.—Carbon Dioxide

Pressure in meters of mercury	Relative values of *pv* at—								
	18°.2	35°.1	40°.2	50°.0	60°.0	70°.0	80°.0	90°.0	100°.0
30	liquid	2360	2460	2590	2730	2870	2995	3120	3225
50	—	1725	1900	2145	2330	2525	2685	2845	2980
80	625	750	825	1200	1650	1975	2225	2440	2635
110	825	930	980	1090	1275	1550	1845	2105	2325
140	1020	1120	1175	1250	1360	1525	1715	1950	2160
170	1210	1310	1360	1430	1520	1645	1780	1975	2135
200	1405	1500	1550	1615	1705	1810	1930	2075	2215
230	1590	1690	1730	1800	1890	1990	2090	2210	2340
260	1770	1870	1920	1985	2070	2166	2265	2375	2490
290	1950	2060	2100	2170	2260	2340	2440	2550	2655
320	2135	2240	2280	2360	2440	2525	2620	2725	2830

Atm.	Relative values of *pv*; *pv* at 0°C and 1 atm. = 1										
	0°	10°	20°	30°	40°	60°	80°	100°	137°	198°	258°
50	0.105	0.114	0.680	0.775	0.750	0.984	1.096	1.206	1.380	—	—
100	0.202	0.213	0.229	0.255	0.309	0.661	0.873	1.030	1.259	1.582	1.847
150	0.295	0.309	0.326	0.346	0.377	0.485	0.681	0.878	1.159	1.530	1.818
300	0.559	0.578	0.599	0.623	0.649	0.710	0.790	0.890	1.108	1.493	1.820
500	0.891	0.913	0.938	0.963	0.990	1.054	1.124	1.201	1.362	1.678	—
1000	1.656	1.685	1.716	1.748	1.780	1.848	1.921	1.999	—	—	—

Amagat, C. R. 111, p. 871, 1890; Ann. chim. phys. (5) 22, p. 353, 1881; (6) 29, pp. 68 and 405, 1893.

COMPRESSIBILITY OF GASES

TABLE 100.—Some Physical Properties of Compressed Nitrogen

(Abridged from Deming, Shupe, Phys. Rev., 37, 639, 1931; based on data by Bartlett and collaborators, Journ. Amer. Chem. Soc., 1927–31.)

Tables published by Bartlett *et al* show compressibility factors $pv/(pv)_s$ at the different pressures and temperatures. The denominator $(pv)_s$ is the value of pv at S.T.P. In order to find the specific volume of the gas it is required to know the volume of 1 g at S.T.P. Birge gives 22414.1 cc as the volume of a mole of an ideal gas at S.T.P.

$pv/(pv)_s$ at 1 atm. is close to 1/1.00046. The gas used by Bartlett contained 0.9993 nitrogen and 0.0007 inert gas, presumably argon; the apparent molecular weight is therefore taken as 28.025. The volume adopted for 1 g at S.T.P. is 22414.1/1.00046 × 28.025 = 799.42 cc, and the value of RT at 0° is 22414.1/28.025 = 799.79 cc atm./g. When one of Bartlett's compressibility factors is divided by the pressure and multiplied by 799.42 the result is the volume in cc of 1 g of the gas at the given temperature and pressure.

For fugacities, see Lewis and Randall, Thermodynamics, 1923.

t °C	p atm.	Sp. vol. cc/g	Density ρ g/cc	f fugacity atm.	$\left(\frac{-p}{v}\cdot\frac{dv}{dp}\right)_T$	$\left(\frac{T}{v}\cdot\frac{dv}{dT}\right)_p$	ΔC_p cal./mole°	Joule-Thomson coefficient μ °/atm.
−70	20	28.50	.03508	19.22	1.053	1.162	.50	.627
	60	8.840	.1131	53.31	1.075	1.530	1.79	.538
	100	5.082	.1968	83.18	1.004	1.806	3.13	.408
	200	2.725	.3669	152.1	.717	1.564	5.17	.128
	400	1.896	.5273	319.2	.403	.918	5.10	−.013
	800	1.508	.6630	976.2	.280	.551	4.97	−.057
	1200	1.358	.7365	2545	.250	.356	4.81	−.074
−50	20	31.75	.03149	19.48	1.031	1.129	.45	.559
	60	10.13	.09872	55.49	1.048	1.381	1.43	.463
	100	5.952	.1680	88.75	1.000	1.560	2.41	.355
	200	3.139	.3186	168.4	.775	1.462	3.76	.136
	400	2.068	.4836	357.8	.472	.937	3.84	−.012
	800	1.591	.6284	1063	.313	.578	3.66	−.064
	1200	1.408	.7103	2645	.286	.404	3.48	−.081
−25	20	35.75	.02798	19.70	1.018	1.094	.36	.470
	60	11.66	.08578	57.43	1.025	1.266	1.14	.383
	100	6.950	.1439	93.70	.900	1.377	1.90	.298
	200	3.645	.2744	183.6	.830	1.363	2.95	.134
	400	2.287	.4372	395.5	.540	.961	3.02	−.008
	800	1.695	.5901	1121	.353	.608	2.72	−.069
	1200	1.473	.6789	2703	.320	.457	2.53	−.085
0	20	39.67	.02521	19.84	1.010	1.068	.29	.387
	60	13.11	.07627	58.72	1.005	1.183	.92	.308
	100	7.886	.1268	97.05	.978	1.265	1.53	.247
	200	4.139	.2416	194.6	.850	1.281	2.34	.125
	400	2.510	.3984	424.2	.590	.983	2.48	−.005
	800	1.798	.5560	1194	.390	.639	2.20	−.071
	1200	1.543	.6481	2732	.350	.503	2.01	−.084
20	20	42.74	.02340	19.92	1.003	1.055	.25	.325
	60	14.23	.07027	59.41	.995	1.140	.75	.263
	100	8.604	.1162	99.06	.970	1.199	1.22	.211
	200	4.524	.2210	201.0	.860	1.223	2.05	.114
	400	2.693	.3713	441.5	.628	.994	2.33	−.002
	800	1.880	.5318	1226	.417	.660	2.13	−.071
	1200	1.601	.6248	2737	.373	.534	1.98	−.083
50	20	47.33	.02113	20.01	.998	1.037	.19	.248
	60	15.87	.06301	60.18	.984	1.099	.54	.208
	100	9.639	.1038	100.9	.961	1.138	.86	.169
	200	5.078	.1969	207.5	.845	1.151	1.46	.094
	400	2.967	.3371	459.7	.670	.995	1.88	−.001
	800	2.010	.4974	1254	.456	.688	1.83	−.071
	1200	1.688	.5925	2719	.402	.566	1.74	−.083
100	20	54.87	.01822	20.08	.995	1.023	.12	.162
	60	18.52	.05400	60.87	.975	1.052	.35	.138
	100	11.29	.08856	102.1	.953	1.078	.56	.114
	200	5.955	.1679	213.7	.881	1.078	1.01	.058
	400	3.421	.2924	476.8	.716	.974	1.53	−.010
	800	2.225	.4494	1271	.515	.720	1.70	−.072
	1200	1.836	.5447	2649	.445	.597	1.98	−.085
300	20	84.64	.01181	20.18	.990	1.003	.05	.010
	60	28.73	.03480	61.62	.970	.997	.14	−.006
	100	17.57	.05692	104.6	.951	.992	.22	−.018
	200	9.230	.1083	219.6	.907	.969	.39	−.042
	400	5.098	.1962	487.4	.808	.894	.64	−.071
	800	3.060	.3268	1218	.658	.751	.91	−.096
	1200	2.387	.4190	2306	.570	.642	1.02	−.107
600	20	128.8	.007766	20.15	.992	.995	.01	−.083
	60	43.57	.02295	61.36	.976	.987	.04	−.090
	100	26.54	.03768	103.9	.961	.978	.06	−.095
	200	13.77	.07264	215.8	.926	.943	.11	−.101
	400	7.409	.1350	466.9	.860	.891	.19	−.110
	800	4.234	.2362	1097	.746	.792	.31	−.117
	1200	3.177	.3148	1938	.670	.720	.35	−.119

TABLE 101.—Compressibility of Gases Under High Pressures

(Bridgman, Proc. Amer. Acad., 59, 173, 1924.)

Actual vols. rest upon Amagat's doubtful values at 3000 kg/cm.² Vol. of gas = 1 cm³ at 0°C, 1 kg/cm² pressure. Densities at highest pressures indicate that the molecules or atoms are very nearly in contact in the sense of the kinetic theory.

	(a).—Results for Hydrogen								(b).—Results for Nitrogen				
kg/cm²	Vol. change c³/g from 3000 kg		Volume c³/g		pv at 65°C	Vol. c³/mol			Vol. change 68°C		Volume at 68°C		pv at 68°C
	30°C	65°C	30°C	65°C		30°C	65°C		c³/g	c²/mol	c³/g	c³/mol	
3000	0.00	0.00	11.64	12.17	3.18	23.47	24.53		.000	0.00	1.290	36.13	4.68
4000	1.12	1.14	10.52	11.03	3.83	21.21	22.24		.089	2.49	1.201	33.64	5.82
5000	1.84	1.88	9.80	10.29	4.50	19.76	20.74		.152	4.25	1.138	31.88	6.89
7000	2.77	2.88	8.87	9.29	5.65	17.88	18.73		.234	6.56	1.056	29.57	8.95
10000	3.63	3.68	8.01	8.49	7.29	16.15	17.12		.308	8.61	.982	27.52	11.91
13000	4.32	4.21	7.32	7.96	8.66	14.76	16.05		.357	10.00	.033	26.13	14.70
15000	...	...	...	...	...	...	...		.382	10.70	.908	25.43	16.50

	(c).—Results for Helium					(d).—Results for Argon		(e).—Results for Ammonia		
kg/cm²	Vol. change c³/g 65°C	Total vol. change 30–95° c³/g	Volume at 65°C		pv at 65°C	Vol. change at 55°		kg/cm²	Vol. change at 30°C	
			c³/g	c³/mol		c³/g	c³/g atom		c³/g	c³/mol
3000	0.00	0.613	5.54	22.16	2.31	0.000	0.00	1000	−0.827	−14.1
4000	0.77	.598	4.77	19.08	2.64	.049	1.96	2000	− .217	− 3.70
5000	1.23	.589	4.31	17.24	2.99	.085	3.39	3000	.000	0.00
7000	1.77	.581	3.77	15.08	3.66	.134	5.34	5000	+ .200	+ 3.41
10000	2.22	.576	3.32	13.27	4.60	.180	7.18	7000	.310	5.28
13000	2.48	.572	3.06	12.24	5.52	.209	8.34	10000	.409	6.97
15000	2.60	.570	2.94	11.76	6.11	.224	8.94	12000	.461	7.85

TABLE 102.—Gage Pressure (lb./in.²) to Atmospheres (absolute)

(Taken from Bur. Standards Circ., 279, 1926.)

lb./in.²	0	10	20	30	40	50	60	70	80	90
0	1.00	1.68	2.36	3.04	3.72	4.40	5.08	5.76	6.44	7.12
100	7.80	8.48	9.17	9.85	10.53	11.21	11.89	12.57	13.25	13.93
200	14.61	15.29	15.97	16.65	17.33	18.01	18.69	19.37	20.05	20.73
300	21.41	22.09	22.77	23.45	24.14	24.82	25.50	26.18	26.86	27.54
400	28.22	28.90	29.58	30.26	30.94	31.62	32.30	32.98	33.66	34.34
500	35.02	35.70	36.38	37.06	37.74	38.42	39.11	39.79	40.47	41.15
600	41.83	42.51	43.19	43.87	44.55	45.23	45.91	46.59	47.27	47.95
700	48.63	49.31	49.99	50.67	51.35	52.03	52.71	53.39	54.08	54.76
800	55.44	56.12	56.80	57.48	58.16	58.84	59.52	60.20	60.88	61.56
900	62.24	62.92	63.60	64.28	64.96	65.64	66.32	67.00	67.68	68.36
1,000	69.04	69.73	70.41	71.09	71.77	72.45	73.13	73.81	74.49	75.17
1,100	75.85	76.53	77.21	77.89	78.57	79.25	79.93	80.61	81.29	81.07
1,200	82.65	83.34	84.01	84.70	85.38	86.06	86.74	87.42	88.10	88.78
1,300	89.46	90.14	90.82	91.50	92.18	92.86	93.54	94.22	94.90	05.58
1,400	96.27	96.95	97.63	98.31	98.98	99.67	100.3	101.0	101.7	102.4
1,500	103.1	103.8	104.4	105.1	105.8	106.5	107.1	107.8	108.5	109.2
1,600	109.9	110.6	111.3	111.9	112.6	113.3	114.0	114.6	115.3	116.0
1,700	116.7	117.4	118.0	118.7	119.4	120.1	120.8	121.4	122.1	122.8
1,800	123.5	124.2	124.8	125.5	126.2	126.9	127.6	128.2	128.9	120.6
1,900	130.3	131.0	131.6	132.3	133.0	133.7	134.4	135.0	135.7	136.4
2,000	137.1	137.8	138.4	139.1	139.8	140.5	141.2	141.9	142.5	143.2
2,100	143.9	144.6	145.2	145.9	146.6	147.3	148.0	148.7	149.3	150.0
2,200	150.7	151.4	152.1	152.7	153.4	154.1	154.8	155.5	156.1	156.8
2,300	157.5	158.2	158.9	159.5	160.2	160.9	161.6	162.3	162.9	163.6
2,400	164.3	165.0	165.7	166.3	167.0	167.7	168.4	169.1	169.8	170.4
2,500	171.1	171.8	172.5	173.2	173.8	174.5	175.2	175.9	176.6	177.2
2,600	177.9	178.6	179.3	180.0	180.6	181.3	182.0	182.7	183.4	184.0
2,700	184.7	185.4	186.1	186.8	187.4	188.1	188.8	189.5	190.2	190.8
2,800	191.5	192.2	192.9	193.6	194.2	194.9	195.6	196.3	197.0	197.7
2,900	198.3	199.0	199.7	200.4	201.1	201.7	202.4	203.1	203.8	204.4

RELATION BETWEEN PRESSURE, TEMPERATURE, AND VOLUME OF SULPHUR DIOXIDE AND AMMONIA*

TABLE 103.—Sulphur Dioxide

Original volume 100000 under one atmosphere of pressure and the temperature of the experiments as indicated at the top of the different columns.

Pressure in Atmos.	Corresponding Volume for Experiments at Temperature — 58°.0	99°.6	183°.2
10	8560	9440	–
12	6360	7800	–
14	4040	6420	–
16	–	5310	–
18	–	4405	–
20	–	4030	–
24	–	3345	–
28	–	2780	3180
32	–	2305	2640
36	–	1935	2260
40	–	1450	2040
50	–	–	1640
60	–	–	1375
70	–	–	1130
80	–	–	930
90	–	–	790
100	–	–	680
120	–	–	545
140	–	–	430
160	–	–	325

Volume.	Pressure in Atmospheres for Experiments at Temperature — 58°.0	99°.6	183°.2
10000	–	9.60	–
9000	9.60	10.35	–
8000	10.40	11.85	–
7000	11.55	13.05	–
6000	12.30	14.70	–
5000	13.15	16.70	–
4000	14.00	20.15	–
3500	14.40	23.00	–
3000	–	26.40	29.10
2500	–	30.15	33.25
2000	–	35.20	40.95
1500	–	39.60	55.20
1000	–	–	76.00
500	–	–	117.20

TABLE 104.—Ammonia

Original volume 100000 under one atmosphere of pressure and the temperature of the experiments as indicated at the top of the different columns.

Pressure in Atmos.	Corresponding Volume for Experiments at Temperature — 46°.6	99°.6	183°.6
10	9500	–	–
12.5	7245	7635	–
15	5880	6305	–
20	–	4645	4875
25	–	3560	3835
30	–	2875	3185
35	–	2440	2680
40	–	2080	2345
45	–	1795	2035
50	–	1490	1775
55	–	1250	1590
60	–	975	1450
70	–	–	1245
80	–	–	1125
90	–	–	1035
100	–	–	950

Volume.	Pressure in Atmospheres for Experiments at Temperature — 30°.2	46°.6	99°.6	183°.0
10000	8.85	9.50		–
9000	9.60	10.45		–
8000	10.40	11.50	12.00	-
7000	11.05	13.00	13.60	–
6000	11.80	14.75	15.55	–
5000	12.00	16.60	18.60	19.50
4000	–	18.35	22.70	24.00
3500	–	18.30	25.40	27.20
3000	–	–	29.20	31.50
2500	–	–	34.25	37.35
2000	–	–	41.45	45.50
1500	–	–	49.70	58.00
1000	–	–	59.65	93.60

* From the experiments of Roth, "Wied. Ann." vol. 11, 1880

Table 105

VOLUME OF GASES

Values of 1 + .00367 *t*

The quantity $1 + .00367\,t$ gives for a gas the volume at t° when the pressure is kept constant, or the pressure at t° when the volume is kept constant, in terms of the volume or the pressure at 0°.

(**a**) This part of the table gives the values of $1 + .00367\,t$ for values of t between 0° and 10° C by tenths of a degree.

(**b**) This part gives the values of $1 + .00367\,t$ for values of t between −90° and +1990° C by 10° steps.

These two parts serve to give any intermediate value to one tenth of a degree by a simple computation as follows: — In the (*b*) table find the number corresponding to the nearest lower temperature, and to this number add the decimal part of the number in the (*a*) table which corresponds to the difference between the nearest temperature in the (*b*) table and the actual temperature. For example, let the temperature be 682°.2:

We have for 680 in table (*b*) the number	3.49560
And for 2.2 in table (*a*) the decimal	.00807
Hence the number for 682.2 is	3.50367

(**c**) This part gives the logarithms of $1 + .00367\,t$ for values of t between −49° and +399° C by degrees.

(**d**) This part gives the logarithms of $1 + .00367\,t$ for values of t between 400° and 1990° C by 10° steps.

(a) Values of 1 + .00367 *t* for Values of *t* between 0 and 10° C by 0.1° Steps

t	0.0	0.1	0.2	0.3	0.4
0	1.00000	1.00037	1.00073	1.00110	1.00147
1	.00367	.00404	.00440	.00477	.00514
2	.00734	.00771	.00807	.00844	.00881
3	.01101	.01138	.01174	.01211	.01248
4	.01468	.01505	.01541	.01578	.01615
5	1.01835	1.01872	1.01908	1.01945	1.01982
6	.02202	.02239	.02275	.02312	.02349
7	.02569	.02606	.02642	.02679	.02716
8	.02936	.02973	.03009	.03046	.03083
9	.03303	.03340	.03376	.03413	.03450

t	0.5	0.6	0.7	0.8	0.9
0	1.00184	1.00220	1.00257	1.00294	1.00330
1	.00550	.00587	.00624	.00661	.00697
2	.00918	.00954	.00991	.01028	.01064
3	.01284	.01321	.01358	.01395	.01431
4	.01652	.01688	.01725	.01762	.01798
5	1.02018	1.02055	1.02092	1.02129	1.02165
6	.02386	.02422	.02459	.02496	.02532
7	.02752	.02789	.02826	.02863	.02899
8	.03120	.03156	.03193	.03290	.03266
9	.03486	.03523	.03560	.03597	.03633

VOLUME OF

(b) Logarithms of 1 + .00367 t for Values

t	0	1	2	3	4	Mean diff. per degree.
— 40	$\bar{1}$.931051	$\bar{1}$.929179	$\bar{1}$.927299	$\bar{1}$.925410	$\bar{1}$.923513	1884
— 30	.949341	.947546	.945744	.943934	.942117	1805
— 20	.966892	.965169	.963438	.961701	.959957	1733
— 10	.983762	.982104	.980440	.978769	.977092	1667
— 0	0.000000	.998403	.996801	.995192	.993577	1605
+ 0	0.000000	0.001591	0.003176	0.004755	0.006329	1582
10	.015653	.017188	.018717	.020241	.021760	1526
20	.030762	.032244	.033721	.035193	.036661	1474
30	.045362	.046796	.048224	.049648	.051068	1426
40	.059488	.060875	.062259	.063637	.065012	1381
50	0.073168	0.074513	0.075853	0.077190	0.078522	1335
60	.086431	.087735	.089036	.090332	.091624	1299
70	.099301	.100567	.101829	.103088	.104344	1259
80	.111800	.113030	.114257	.115481	.116701	1226
90	.123950	.125146	.126339	.127529	.128716	1191
100	0.135768	0.136933	0.138094	0.139252	0.140408	1158
110	.147274	.248408	.149539	.150667	.151793	1129
120	.158483	.159588	.160691	.161790	.162887	1101
130	.169410	.170488	.171563	.172635	.173705	1074
140	.180068	.181120	.182169	.183216	.184260	1048
150	0.190472	0.191498	0.192523	0.193545	0.194564	1023
160	.200632	.201635	.202635	.203634	.204630	1000
170	.210559	.211540	.212518	.213494	.214468	976
180	.220265	.221224	.222180	.223135	.224087	956
190	.229759	.230697	.231633	.232567	.233499	935
200	0.239049	0.239967	0.240884	0.241798	0.242710	916
210	.248145	.249044	.249942	.250837	.251731	897
220	.257054	.257935	.258814	.259692	.260567	878
230	.265784	.266648	.267510	.268370	.269228	861
240	.274343	.275189	.276034	.276877	.277719	844
250	0.282735	0.283566	0.284395	0.285222	0.286048	828
260	.290969	.291784	.292597	.293409	.294219	813
270	.299049	.299849	.300648	.301445	.302240	798
280	.306982	.307768	.308552	.309334	.310115	784
290	.314773	.315544	.316314	.317083	.317850	769
300	0.322426	0.323184	0.323941	0.324696	0.325450	756
310	.329947	.330692	.331435	.332178	.332919	743
320	.337339	.338072	.338803	.339533	.340262	730
330	.344608	.345329	.346048	.346766	.347482	719
340	.351758	.352466	.353174	.353880	.354585	707
350	0.358791	0.359488	0.360184	0.360879	0.361573	696
360	.365713	.366399	.367084	.367768	.368451	684
370	.372525	.373201	.373875	.374549	.375221	674
380	.379233	.379898	.380562	.381225	.381887	664
390	.385439	.386494	.387148	.387801	.388453	654

GASES.

of t between $-49°$ and $+399°$ C by 1° Steps

t	5	6	7	8	9	Mean diff. per degree.
−40	$\bar{1}$.921608	$\bar{1}$.919695	$\bar{1}$.917773	$\bar{1}$.915843	$\bar{1}$.913904	1926
−30	.940292	.938460	.936619	.934771	.932915	1845
−20	.958205	.956447	.954681	.952909	.951129	1771
−10	.975409	.973719	.972022	.970319	.968609	1699
−0	.991957	.990330	.988697	.987058	.985413	1636
+0	0.007897	0.009459	0.011016	0.012567	0.014113	1554
10	.023273	.024781	.026284	.027782	.029274	1500
20	.038123	.039581	.041034	.042481	.043924	1450
30	.052482	.053893	.055298	.056699	.058096	1402
40	.066382	.067748	.069109	.070466	.071819	1359
50	0.079847	0.081174	0.082495	0.083811	0.085123	1315
60	.092914	.094198	.095486	.096765	.098031	1281
70	.105595	.106843	.108088	.109329	.110566	1243
80	.117917	.119130	.120340	.121547	.122750	1210
90	.129899	.131079	.132256	.133430	.134601	1175
100	0.141559	0.142708	0.143854	0.144997	0.146137	1144
110	.152915	.154034	.155151	.156264	.157375	1115
120	.163981	.164072	.166161	.167246	.168330	1087
130	.174772	.175836	.176898	.177958	.179014	1060
140	.185301	.186340	.187377	.188411	.189443	1035
150	0.195581	0.196596	0.197608	0.198619	0.199626	1011
160	.205624	.206615	.207605	.208592	.209577	988
170	.215439	.216409	.217376	.218341	.219304	966
180	.225038	.225986	.226932	.227876	.228819	946
190	.234429	.235357	.236283	.237207	.238129	925
200	0.243621	0.244529	0.245436	0.246341	0.247244	906
210	.252623	.253512	.254400	.255287	.256172	887
220	.261441	.262313	.263184	.264052	.264919	870
230	.270085	.270940	.271793	.272644	.273494	853
240	.278559	.279398	.280234	.281070	.281903	836
250	0.286872	0.287694	0.288515	0.289326	0.290153	820
260	.295028	.295835	.296640	.297445	.298248	805
270	.303034	.303827	.304618	.305407	.306196	790
280	.310895	.311673	.312450	.313226	.314000	776
290	.318616	.319381	.320144	.320906	.321667	763
300	0.326203	0.326954	0.327704	0.328453	0.329201	750
310	.333659	.334397	.335135	.335871	.336606	737
320	.340989	.341715	.342441	.343164	.343887	724
330	.348198	.348912	.349624	.350337	.351048	713
340	.355289	.355991	.356693	.357394	.358093	701
350	0.362266	0.362957	0.363648	0.364337	0.365025	690
360	.369132	.369813	.370493	.371171	.371849	678
370	.375892	.376562	.377232	.377900	.378567	668
380	.382548	.383208	.383868	.384525	.385183	658
390	.389104	.389754	.390403	.391052	.391699	648

VOLUME OF GASES

(c) Values of $1 + .00367t$ for Values of t between $-90°$ and $+2090°$ C by 10° Steps

t	00	10	20	30	40
−000	1.00000	0.96330	0.92660	0.88990	0.85320
+000	1.00000	1.03670	1.07340	1.11010	1.14680
100	1.36700	1.40370	1.44040	1.47710	1.51380
200	1.73400	1.77070	1.80740	1.84410	1.88080
300	2.10100	2.13770	2.17440	2.21110	2.24780
400	2.46800	2.50470	2.54140	2.57810	2.61480
500	2.83500	2.87170	2.90840	2.94510	2.98180
600	3.20200	3.23870	3.27540	3.31210	3.34880
700	3.56900	3.60570	3.64240	3.67910	3.71580
800	3.93600	3.97270	4.00940	4.04610	4.08280
900	4.30300	4.33970	4.37640	4.41310	4.44980
1000	4.67000	4.70670	4.74340	4.78010	4.81680
1100	5.03700	5.07370	5.11040	5.14710	5.18380
1200	5.40400	5.44070	5.47740	5.51410	5.55080
1300	5.77100	5.80770	5.84440	5.88110	5.91780
1400	6.13800	6.17470	6.21140	6.24810	6.28480
1500	6.50500	6.54170	6.57840	6.61510	6.65180
1600	6.87200	6.90870	6.94540	6.98210	7.01880
1700	7.23900	7.27570	7.31240	7.34910	7.38580
1800	7.60600	7.64270	7.67940	7.71610	7.75280
1900	7.97300	8.00970	8.04640	8.08310	8.11980
2000	8.34000	8.37670	8.41340	8.45010	8.48680

t	50	60	70	80	90
−000	0.81650	0.77980	0.74310	0.70640	0.66970
+000	1.18350	1.22020	1.25690	1.29360	1.33030
100	1.55050	1.58720	1.62390	1.66060	1.69730
200	1.91750	1.95420	1.99090	2.02760	2.06430
300	2.28450	2.32120	2.35790	2.39460	2.43130
400	2.65150	2.68820	2.72490	2.76160	2.79830
500	3.01850	3.05520	3.09190	3.12860	3.16530
600	3.38550	3.42220	3.45890	3.49560	3.53230
700	3.75250	3.78920	3.82590	3.86260	3.89930
800	4.11950	4.15620	4.19290	4.22960	4.26630
900	4.48650	4.52320	4.55990	4.59660	4.63330
1000	4.85350	4.89020	4.92690	4.96360	5.00030
1100	5.22050	5.25720	5.29390	5.33060	5.36730
1200	5.58750	5.62420	5.66090	5.69760	5.73430
1300	5.95450	5.99120	6.02790	6.06460	6.10130
1400	6.32150	6.35820	6.39490	6.43160	6.46830
1500	6.68850	6.72520	6.76190	6.79860	6.83530
1600	7.05550	7.09220	7.12890	7.16560	7.20230
1700	7.42250	7.45920	7.49590	7.53260	7.56930
1800	7.78950	7.82620	7.86290	7.89960	7.93630
1900	8.15650	8.19320	8.22990	8.26660	8.30330
2000	8.52350	8.56020	8.59690	8.63360	8.67030

VOLUME OF GASES

(d) Logarithms of $1 + .00367\,t$ for Values of t between 400° and 1990° C by 10° Steps

t	00	10	20	30	40
400	0.392345	0.398756	0.405073	0.411300	0.417439
500	0.452553	0.458139	0.463654	0.469100	0.474479
600	.505421	.510371	.515264	.520103	.524889
700	.552547	.556990	.561388	.565742	.570052
800	.595055	.599086	.603079	.607037	.610958
900	.633771	.637460	.641117	.644744	.648341
1000	0.669317	0.672717	0.676090	0.679437	0.682759
1100	.702172	.705325	.708455	.711563	.714648
1200	.732715	.735655	.738575	.741475	.744356
1300	.761251	.764004	.766740	.769459	.772160
1400	.788027	.790616	.793190	.795748	.798292
1500	0.813247	0.815691	0.818120	0.820536	0.822939
1600	.837083	.839396	.841697	.843986	.846263
1700	.859679	.861875	.864060	.866234	.868398
1800	.881156	.883247	.885327	.887398	.889459
1900	.901622	.903616	.905602	.907578	.909545

t	50	60	70	80	90
400	0.423492	0.429462	0.435351	0.441161	0.446894
500	0.479791	0.485040	0.490225	0.495350	0.500415
600	.529623	.534305	.538938	.543522	.548058
700	.574321	.578548	.582734	.586880	.590987
800	.614845	.618696	.622515	.626299	.630051
900	.651908	.655446	.658955	.662437	.665890
1000	0.686055	0.689327	0.692574	0.695797	0.698996
1100	.717712	.720755	.723776	.726776	.729756
1200	.747218	.750061	.752886	.755692	.758480
1300	.774845	.777514	.780166	.782802	.785422
1400	.800820	.803334	.805834	.808319	.810790
1500	0.825329	0.827705	0.830069	0.832420	0.834758
1600	.848528	.850781	.853023	.855253	.857471
1700	.870550	.872692	.874824	.876945	.879056
1800	.891510	.893551	.895583	.897605	.899618
1900	.911504	.913454	.915395	.917327	.919251

TABLE 106

COMPRESSIBILITY OF LIQUIDS

At the constant temperature t, the compressibility $\beta = (1/V_0)(dV/dP)$. In general as P increases, β decreases rapidly at first and then slowly; the change of β with t is large at low pressures but very small at pressures above 1000 to 2000 megabaryes. 1 megabarye $= 10^6$ dynes/cm^2 = 1.020 kg/cm^2 = 0.987 atmosphere.

Substance.	Temp. °C	Pressure, megabaryes.	Compressibility per megabaryes. $\beta \times 10^6$.	Reference.
Acetone	14	23	111	9
"	20	500	61	1
"	20	1,000	52	1
"	40	12,000	9	1
Amyl alcohol	14	23	88	10
" " iso	20	200	84	16
" " iso	20	400	70	16
" "	20	500	61	1
" "	20	1,000	46	1
" "	20	12,000	8	1
" "	40	12,000	8	1
Benzene	17	5	89	2, 3
"	20	200	77	16
"	20	400	67	16
Bromine	20	200	56	16
"	20	400	51	16
Butyl alcohol, iso	18	8	97	2
" " iso	20	200	81	16
" " iso	20	400	64	16
" " iso	20	500	56	1
" " iso	20	1,000	46	1
" " iso	20	12,000	8	1
Carbon bisulphide	16	21	86	10
" "	20	500	57	1
" "	20	1,000	48	1
" "	20	12,000	6	1
Carb. tetrachloride	20	200	86	16
" "	20	400	73	16
Chloroform	20	200	83	16
"	20	400	70	16
Dichlorethylsulfide	32	1,000	34	5
"	32	2,000	24	5
Ethyl acetate	13	23	103	10
" "	20	200	90	16
" "	20	400	75	16
Ethyl alcohol	14	23	100	10
" "	20	500	63	1
" "	20	1,000	54	1
" "	20	12,000	8	1
Ethyl bromide	20	200	100	16
" "	20	400	82	16
" "	20	500	70	1
" "	20	1,000	54	1
" "	20	12,000	8	1
Ethyl chloride	15	23	151	10
" "	20	500	102	1
" "	20	1,000	66	1
" "	20	12,000	8	1
Ethyl ether	25	23	188	10
" "	20	500	84	1

Substance.	Temp. °C	Pressure, megabaryes.	Compressibility per megabaryes. $\beta \times 10^6$.	Reference.
Ethyl ether, ct'd	20	1,000	61	1
" " "	20	12,000	10	1
Ethyl iodide	20	200	81	16
" "	20	400	69	16
" "	20	500	64	1
" "	20	1,000	50	1
" "	20	12,000	8	1
Gallium	30	300	3.97	6
Glycerine	15	5	22	12
Hexane	20	200	117	16
"	20	400	91	16
Kerosene	20	500	55	1
"	20	1,000	45	1
"	20	12,000	8	1
"	20	12,000	8	13
Mercury	20	300	3.95	7
"	22	500	3.97	8
"	22	1,000	3.91	8
"	22	12,000	2.37	8
Methyl alcohol	15	23	103	10
" "	20	200	95	16
" "	20	400	80	16
" "	20	500	65	1
" "	20	1,000	54	1
" "	20	12,000	8	1
Nitric acid	0	17	32	14
Oils: Almond	15	5	53	12
Castor	15	5	46	12
Linseed	15	5	51	12
Olive	15	5	55	12
Rape-seed	20	—	59	15
Phosph. trichloride	10	250	71	11
" "	20	500	63	1
" "	20	1,000	47	1
" "	20	12,000	8	1
Propyl alcohol, n.	20	200	77	16
" " n.	20	400	67	16
" " (n?)	20	500	65	1
" " (n?).	20	1,000	47	1
" " (n?).	20	12,000	7	1
Toluene	20	200	74	16
"	20	400	64	16
Turpentine	20	—	74	15
Water	20	13	49	11
"	20	200	43	16
"	20	400	41	16
"	20	500	39	4
"	40	500	38	4
"	40	1000	33	4
"	40	12,000	9	4
Xylene, meta	20	200	69	16
" "	20	400	60	16

For references, see page 156.

Table 107

COMPRESSIBILITY AND THERMAL EXPANSION OF PETROLEUM OILS,

0-50 kg/cm², 0-400°C

(R. S. Jessup, Bur. Standards Journ. Res., 5, 985, 1930.)

It was found that the compressibility and thermal expansion of two samples of the same specific gravity, but from different sources, differed more than 30 per cent at the higher temperatures, whereas oils of the same specific gravity and the same viscosity had the same compressibility and thermal expansion within rather narrow limits. In other words, with a knowledge of the specific gravity and viscosity of the oils, it was possible to represent all the measured volumes within less than 0.5 per cent over the entire range of temperature and pressure covered by the measurements.

Kinematic viscosity 100°F., c.g.s.	Specific gravity 60°/60°F.	Pressure kg/cm²	Relative volumes						
			0°	20°	50°	100°	200°	300°	400°
.020	.80	0	1.000	1.018	1.045	1.096	1.222	1.422	....
"	"	50	0.996	1.014	1.041	1.089	1.205	1.370	(1.63)
"	.85	0	1.000	1.017	1.044	1.093	1.213	1.396	(1.71)
"	"	50	0.997	1.014	1.040	1.086	1.197	1.352	(1.58)
"	.90	0	1.000	1.017	1.043	1.090	1.204	1.375	(1.67)
"	"	50	0.997	1.013	1.038	1.084	1.191	1.337	(1.55)
.050	.80	0	1.000	1.017	1.043	1.089	1.202	1.369	(1.71)
"	"	50	0.997	1.013	1.038	1.083	1.189	1.333	(1.56)
"	.85	0	1.000	1.016	1.041	1.087	1.194	1.349	(1.63)
"	"	50	0.997	1.013	1.037	1.081	1.182	1.318	(1.51)
"	.90	0	1.000	1.016	1.040	1.084	1.188	1.331	(1.56)
"	"	50	0.997	1.012	1.036	1.078	1.176	1.304	(1.48)
.100	.85	0	1.000	1.016	1.040	1.083	1.185	1.325	(1.54)
"	"	50	0.997	1.012	1.036	1.078	1.174	1.299	(1.47)
"	.95	0	1.000	1.015	1.038	1.079	1.174	1.297	(1.47)
"	"	50	0.997	1.012	1.034	1.074	1.164	1.276	(1.43)
.500	.85	0	1.000	1.015	1.038	1.078	1.170	1.289	(1.45)
"	"	50	0.997	1.012	1.034	1.073	1.161	1.269	(1.41)
"	.95	0	1.000	1.014	1.036	1.074	1.161	1.269	(1.40)
"	"	50	0.998	1.012	1.033	1.070	1.152	1.252	(1.37)
1.000	.85	0	1.000	1.015	1.037	1.076	1.165	1.279	(1.43)
"	"	50	0.997	1.012	1.034	1.071	1.157	1.260	(1.39)
"	.95	0	1.000	1.014	1.035	1.073	1.157	1.261	(1.39)
"	"	50	0.998	1.011	1.032	1.068	1.149	1.244	(1.36)
2.000	.85	0	1.000	1.014	1.036	1.075	1.162	1.270	(1.41)
"	"	50	0.998	1.011	1.033	1.070	1.153	1.253	(1.37)
"	.95	0	1.000	1.014	1.035	1.071	1.153	1.254	(1.37)
"	"	50	0.998	1.011	1.032	1.067	1.145	1.239	(1.35)
5.000	.85	0	1.000	1.014	1.035	1.073	1.157	1.261	(1.39)
"	"	50	0.998	1.011	1.032	1.068	1.149	1.245	(1.36)
"	.95	•	1.000	1.013	1.034	1.069	1.148	1.244	(1.36)
"	"	50	0.998	1.011	1.031	1.065	1.141	1.229	(1.33)
210°F., c.g.s.	60°/60°F.	kg/cm²	0°	20°	50°	100°	200°	300°	400°
.100	.90	0	1.000	1.014	1.036	1.074	1.161	1.269	(1.41)
"	"	50	0.998	1.011	1.032	1.070	1.152	1.252	(1.37)
"	.95	0	1.000	1.014	1.035	1.071	1.154	1.256	(1.38)
"	"	50	0.998	1.011	1.032	1.067	1.147	1.241	(1.35)
"	1.00	0	1.000	1.014	1.034	1.070	1.149	1.247	(1.37)
"	"	50	0.998	1.011	1.031	1.066	1.142	1.232	(1.34)
.200	.90	0	1.000	1.014	1.035	1.072	1.155	1.258	(1.39)
"	"	50	0.998	1.011	1.031	1.067	1.147	1.241	(1.35)
"	1.00	0	1.000	1.013	1.033	1.067	1.144	1.237	(1.35)
"	"	50	0.998	1.011	1.030	1.064	1.137	1.223	(1.32)
.440	.90	0	1.000	1.013	1.034	1.070	1.151	1.248	(1.36)
"	"	50	0.998	1.011	1.031	1.066	1.143	1.234	(1.34)
"	1.00	0	1.000	1.012	1.032	1.066	1.140	1.228	(1.33)
"	"	50	0.998	1.010	1.029	1.063	1.134	1.214	(1.31)
1.100	.90	0	1.000	1.013	1.033	1.068	1.146	1.241	(1.35)
"	"	50	0.998	1.010	1.030	1.065	1.139	1.225	(1.33)
"	1.00	0	1.000	1.012	1.031	1.063	1.134	1.218	(1.32)
"	"	50	0.998	1.010	1.028	1.060	1.128	1.205	(1.29)

TABLE 108

COMPRESSIBILITY OF SOLIDS

If V is the volume of the material under a pressure P megabaryes and V_0 is the volume at atmospheric pressure, then the compressibility $\beta = -(1/V_0)(dV/dP)$. Its unit is cm²/megadynes (reciprocal megabaryes). $10^6/\beta$ is the bulk modulus in absolute units (dynes/cm²). The following values of β, arranged in order of increasing compressibility, are for $P = 0$ and room temperature. 1 megabarye = 10^6 dynes/cm² = 1.020 kg/cm² = 0.987 atmosphere.

Substance	Compression per unit vol. per megabarye $\times 10^6$	Bulk modulus, dynes/cm² $\times 10^{12}$	Reference	Substance	Compression per unit vol. per megabarye $\times 10^6$	Bulk modulus, dynes/cm² $\times 10^{12}$	Reference
Tungsten	0.27	3.7	2	Plate glass	2.23	0.45	4
Boron	0.3	3.0	2	Lead	2.27	0.44	1, 2
Silicon	0.32	3.1	2	Thallium	2.3	0.43	2
Platinum	0.38	2.6	2	Antimony	2.4	0.42	2
Nickel	0.43	2.3	2	Quartz	2.7	0.37	1
Molybdenum	0.46	2.2	2	Magnesium	2.9	0.34	2
Tantalum	0.53	1.9	2	Bismuth	3.0	0.33	1
Palladium	0.54	1.9	2	Graphite	3.0	0.33	2
Cobalt	0.55	1.82	9	Silica glass	3.1	0.32	1
Nichrome	0.56	1.79	9	Cerium	3.6	0.27	9
Iron	0.60	1.67	3	Sodium chloride	4.12	0.24	1
Gold	0.60	1.67	1, 2	Arsenic	4.5	0.22	2
Pyrite	0.7	1.4	4	Calcium	5.7	0.175	2
Copper	0.75	1.33	1	Potassium chloride	7.4	0.135	6
Manganese	0.84	1.19	2	Strontium	8.4	0.120	9
Brass	0.89	1.12	1	Lithium	9.0	0.111	2
Chromium	0.9	1.12	1	Phosphorus (red)	9.2	0.109	2
Silver	0.99	1.01	1, 2	Selenium	12.0	0.083	2
Mg. silicate, crys.	1.03	0.97	4	Ice	12.0	0.083	8
Mg. silicate	1.21	0.82	7	Sulphur	12.9	0.078	2
Aluminum	1.33	0.75	1–3	Iodine	13.0	0.077	2
Calcite	1.39	0.72	1	Sodium	15.6	0.064	2
Germanium	1.40	0.71	9	Hard rubber	19.4		7
Zinc	1.74	0.57	1	Phosphorus (white)	20.5	0.049	2
Tin	1.89	0.53	1	Potassium	31.7	0.032	2
Gallium	2.09	0.48	5	Rubidium	40.0	0.025	2
Cadmium	2.17	0.46	1, 2	Caesium	61.0	0.016	2

Winklemann, Schott, and Straulel (Wied Ann., 1897, 1899) give the following (among others) for Jena glasses in terms of the volume decrease divided by the increase of pressure expressed in kg/mm².

No.	Glass	Bulk moduli	No.	Glass	Bulk moduli
665	....	7520	2154	Kalibleisilicat	3660
1299	Barytborosilicat	5800	S208	Heaviest Bleisilicat	3550
16	Natronkalkzinksilicat	4530	S196	Tonerdborat with sodium, baryte	3470

These values are in cm²/kg × 10⁶ × Compressibility, Grüneisen, Ann. der Phys. 33, p. 65, 1910.

Al — 191°, 1.32; 17°, 1.46; 125°, 1.70
Cu — 191°, 0.72; 17°, 0.77; 165°, 0.83
Pt — 189°, 0.37; 17°, 0.39; 164°, 0.40
Fe — 190°, 0.61; 18°, 0.63; 165°, 0.67
Ag — 191°, 0.71; 16°, 0.76; 166°, 0.86
Pb — 191°, (2.5); 14°, (3.2)

References to Table 106, p. 154:

(1) Bridgman, Pr. Am. Acad. 49, 1, 1913;
(2) Roentgen, Ann. Phys. 44, 1, 1891;
(3) Pagliani-Palazzo, Mem. Acad. Lin. 3, 18, 1883;
(4) Bridgman, Pr. Am. Acad. 48, 341, 1912;
(5) Adams, Williamson, J. Wash. Acad. Sc. 9, Jan. 19, 1919;
(6) Richards, Boyer, Pr. Nat. Acad. Sc. 4, 389, 1918;
(7) Richards, J. Am. Ch. Soc. 37, 1646, 1915;
(8) Bridgman, Pr. Am. Acad. 47, 381, 1911;
(9) Amagat, C. R. 73, 143, 1872;
(10) Amagat, C. R. 68, 1170, 1869;
(11) Amagat, Ann. chim. phys. 29, 68, 505, 1893;
(12) de Metz, Ann. Phys. 41, 663, 1890;
(13) Adams, Williamson, Johnston, J. Am. Chem. Soc. 41, 27, 1919;
(14) Colladon, Sturm, Ann. Phys. 12, 39, 1828;
(15) Quincke, Ann. Phys. 19, 401, 1883;
(16) Richards *et al.* J. Am. Ch. Soc. 34, 988, 1912.

References to Table 108, p. 156:

(1) Adams, Williamson, Johnston, J. Am. Ch. Soc. 41, 39, 1919;
(2) Richards, *ibid.* 37, 1646, 1915;
(3) Bridgman, Pr. Am. Acad. 44, 279, 1909; 47, 366, 1911;
(4) Adams, Williamson, unpublished;
(5) Richards, Boyer, Pr. Nat. Acad. Sc. 4, 388, 1918;
(6) Voigt, Ann. Phys. 31, 1887; 36, 1888;
(7) R. E. Gibson, L. H. Adams, unpublished;
(8) Bridgman, Pr. Am. Acad., 48, 310, 1912;
(9) Bridgman, Pr. Am. Acad., 58, 166, 1923.

Table 109

COMPRESSIBILITY OF CRYSTALS

Crystal	System		Linear, $L/L_0 = ap - bp^2$		Volume, $V/V_0 = ap - bp^2$			
			30°C		30°C		75°C	
			$a \times 10^6$	$b \times 10^{12}$	$a \times 10^6$	$b \times 10^{12}$	$a \times 10^6$	$b \times 10^{12}$
Quartz	Trigonal	‖ *	0.7052	6.44	2.658	24.4	2.705	25.0
		⊥ *	.9764	7.79				
Hanksite	Hexagonal	‖	1.1651	12.34	2.413	24.8	2.509	26.9
		⊥	.624	5.31				
Orthoclase	Monoclinic	A	.9944	5.09	2.085	15.3	2.078	14.8
		B	.5490	5.15				
		C	.4599	1.68				
		Y	1.0765	7.14				
Galena	Cubic		.6122	2.48	1.837	6.33	1.893	7.14
Barite	Orthorhom	A	.4940	3.57	1.729	12.70	1.760	13.44
		B	.6695	4.34				
		C	.5660	3.81				
Celestite	Orthorhom	A	.6268	3.67	1.528	7.20	1.545	8.67
		B	.4476	2.59				
		C	.4537	1.70				
Calcite	Trigonal	‖	.8071	3.26	1.345	4.16	1.370	4.38
		⊥	.2688	.70				
Sphalerite	Cubic†		.427	.70	1.281	1.56	1.257	1.56
Fluorite	Cubic		.4019	2.39	1.206	6.69	1.238	6.75
Apatite	Hexagonal	‖	.2410	.35	1.0730	5.34	1.0910	5.07
		⊥	.4160	2.31				
Jeffersonite	Monoclinic	A	.3093	2.02	.8947	5.21	.9400	6.79
		B	.3924	1.74				
		C	.3078	2.51				
		Y	.1945	.70				
Tourmaline	Trigonal	‖	.478	1.59	.804	3.18	.849	3.37
(black)		⊥	.163	.70				
Cobaltite	Cubic		.2519	1.01	.756	2.85	.768	2.82
Spodumene	Monoclinic	A	.1801	.70	.6930	2.84	.6969	3.50
		B	.2459	.70				
		C	.1997	.70				
		Y	.2474	1.28				
Pyrite	Cubic		.2243	.70	.673	1.95	.671	1.95
Andradite	Cubic		.2210	.70	.6630	2.25	.6606	2.25
Topaz	Orthorhom	A	.2145	.70	.6024	2.32	.5991	2.32
		B	.1486	.70				
		C	.2393	.70				
Magnetite	Cubic		.1799	.70	.5397	2.01	.5376	2.01
Garnet	Cubic		.1793	.73	.5379	2.19	.5439	2.19

* These symbols relate to the corresponding trigonal, tetragonal, hexagonal, axes respectively. † Transition above 9000°. Data from Bridgman, Amer. Journ. Sci., 10, Dec., 1925; 15, Apr., 1928. Unit of pressure kg/cm². The following additional crystal volume compressibilities have been taken from Madelung, Fuchs, Ann. Phys., 65, 305, 1921. Their unit of pressure is dynes $\times 10^6$ per cm² at 0°C. 1 dyne/cm² equals 1.020×10^{-6} kg/cm².

Sylvite, KCl	5.62	Anhydrite, $CaSO_4$	1.76	Zincite, ZnO	0.77
Halite, NaCl	4.14	Strontianite, $SrCO_3$	1.74	Periclase, MgO	0.71
$AgNo_3$	3.67	Aragonite, $CaCO_3$	1.53	Hematite (specular)	0.59
Bismuthinite, Bi_2S_3	3.31	Rhodocrosite, $MnCO_3$	1.3	Rutile, TiO_2	0.58
Argentite, Ag_2S	3.00	Chalcopyrite, $CuFeS_2$	1.28	Ilmenite, $(FeTi)_2O_3$	0.55
Gypsum	2.52	Dolomite, $CaCO_3MgCO_3$	1.21	Cassiterite, SnO	0.48
Witherite, $BaCO_3$	2.02	Hematite, Fe_2O_3	1.08	Sapphire	0.43
Anglesite, $PbSO_4$	(1.93)	Siderite, $FeCO_3$	0.99	Corundum, Al_2O_3	0.38
Cerusite, $PbCO_3$	1.90	Zircon, SiO_2ZnO_2	0.85		
Andularia, $K_2Al_2Si_6O_{16}$	1.79	Marcasite, FeS_2	0.81		

TABLE 110. — Specific Gravities Corresponding to the Baumé Scale

The specific gravities are for 15.56°C (60°F.) referred to water at the same temperature as unity. For specific gravities less than unity the values are calculated from the formula:

$$\text{Degrees Baumé} = \frac{140}{\text{Specific Gravity}} - 130.$$

For specific gravities greater than unity from:

$$\text{Degrees Baumé} = 145 - \frac{145}{\text{Specific Gravity}}.$$

Specific Gravities less than 1.

Specific Gravity.	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	Degrees Baumé.									
0.60	103.33	99.51	95.81	92.22	88.75	85.38	82.12	78.95	75.88	72.90
.70	70.00	67.18	64.44	61.78	59.19	56.67	54.21	51.82	49.49	47.22
.80	45.00	42.84	40.73	38.68	36.67	34.71	32.79	30.92	29.09	27.30
.90	25.56	23.85	22.17	20.54	18.94	17.37	15.83	14.33	12.86	11.41
1.00	10.00									

Specific Gravities greater than 1.

Specific Gravity.	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	Degrees Baumé.									
1.00	0.00	1.44	2.84	4.22	5.58	6.91	8.21	9.49	10.74	11.97
1.10	13.18	14.37	15.54	16.68	17.81	18.91	20.00	21.07	22.12	23.15
1.20	24.17	25.16	26.15	27.11	28.06	29.00	29.92	30.83	31.72	32.60
1.30	33.46	34.31	35.15	35.98	36.79	37.59	38.38	39.16	39.93	40.68
1.40	41.43	42.16	42.89	43.60	44.31	45.00	45.68	46.36	47.03	47.68
1.50	48.33	48.97	49.60	50.23	50.84	51.45	52.05	52.64	53.23	53.80
1.60	54.38	54.94	55.49	56.04	56.58	57.12	57.65	58.17	58.69	59.20
1.70	59.71	60.20	60.70	61.18	61.67	62.14	62.61	63.08	63.54	63.99
1.80	64.44	64.89	65.33	65.76	66.20	66.62				

TABLE 111. Degrees A. P. I. Corresponding to Specific Gravities at 60°/60° F.

(15.56°/15.56° C) for petroleum oils.

In order to avoid confusion and misunderstanding the American Petroleum Institute, the Bureau of Mines, and the Bureau of Standards have agreed that a scale based on the modulus 141.5 shall be used in the United States Petroleum Industry and shall be known as the A. P. I. scale. The United States Baumé scale based on the modulus 140 will continue to be used for other liquids lighter than water.

$$\text{Calculated from the formula, degrees A. P. I.} = \frac{141.5}{\text{Sp. Gr. } 60°/60° \text{ F}} - 131.5$$

Degrees A. P. I. 60°/60° F.	0	1	2	3	4	5	6	7	8	9
0.6	104.33	100.47	96.73	93.10	89.59	86.19	82.89	79.69	76.59	73.57
.7	70.64	67.80	65.03	62.34	59.72	57.17	54.68	52.27	49.91	47.61
.8	45.38	43.19	44.06	38.98	36.95	34.97	33.03	31.14	29.30	27.49
.9	25.72	23.99	22.30	20.65	19.03	17.45	15.90	14.38	12.89	11.43
1.0	10.00									

TABLE 112

DENSITY OF THE ELEMENTS, LIQUID OR SOLID

The density may depend considerably on previous treatment.
To reduce to lbs./cu. ft. multiply by 62.4.

Element	Physical State	g/cm³	°C*	Authority
Aluminum	commercial h'd d'n	2.70	20°	Wolf, Dellinger, 1910
"	liquid	2.43	740	
"	"	2.29	1000	Edwards, Taylor
Antimony	vacuo-distilled	6.618	20	Kahlbaum, 1902
"	ditto-compressed	6.691	20	" "
"	amorphous	6.22		Hérard
"	liquid	6.55	631	Pascal, Jauniaux
Argon	"	1.40	−186	Baly-Donnan
"	solid	1.65	−233	Simon, 1924
Arsenic	crystallized	5.73	14	
"	amorph. br.-black	3.70		Geuther
"	yellow	3.88		Linck
Barium	solid	3.78		Guntz
Bismuth	electrolytic	9.747		Classen, 1890
"	vacuo-distilled	9.781	20	Kahlbaum, 1902
"	liquid	10.00	271	Vincentini-Omodei
"	solid	9.67	271	" "
Boron	crystal	2.535		Wigand
"	amorph. pure	2.45		Moissan
Bromine	liquid	3.12		Richards-Stull
"	solid	4.2	−273	Computed†
Cadmium	wrought	8.67		
"	vacuo-distilled	8.648	20	Kahlbaum, 1902
"	solid	8.37	318	Vincentini-Omodei
"	liquid	7.99	318	" "
Cæsium	solid	1.873	20	Richards-Brink
"	liquid	1.836	27	Eckardt, Graefe, 1900
Calcium		1.54		Brink
Carbon	diamond	3.52		Wigand
"	graphite	2.25		"
Cerium	electrolytic	6.79		Muthmann-Weiss
"	pure	7.02		" "
Chlorine	liquid	1.507	− 33.6	Drugman-Ramsay
"	solid	2.2	−273	Computed†
Chromium		6.52–6.73		
"	pure	6.93	25	Peffer, 1931
Cobalt		8.71	21	Tilden, Ch. C., 1898
Columbium		8.4	15	Muthmann-Weiss
Copper	cast	8.30–8.95		
"	annealed	8.89	20	Dellinger, 1911
"	hard drawn	8.89	20	" "
"	vacuo-distilled	8.9326	20	Kahlbaum, 1902
"	ditto-compressed	8.9376	20	" "
"	liquid	8.217		Roberts-Wrightson
Erbium		4.77		St. Meyer, Z. Ph. Ch. 37
Fluorine	liquid	1.14	−200	Moissan-Dewar
"	solid	1.5	−273	Computed†
Gallium		5.93	23	de Boisbaudran
Germanium		5.46	20	Winkler
Glucinum		1.85		Humpidge
Gold	cast	19.3		
"	vacuo-distilled	18.88	20	Kahlbaum, 1902
"	ditto-compressed	19.27	20	" "
Hafnium	solid	13.3		de Boer, 1930
Helium	liquid	0.15	−269	Onnes, 1908
"	solid	0.19	−273	Computed†
Hydrogen	liquid	0.070	−252	Dewar, Ch. News, 1904
"	solid	0.763	−260	Dewar
Indium		7.28		Richards

* Where the temperature is not given, ordinary temperature is understood. † Herz, 1919.

DENSITY OF THE ELEMENTS, LIQUID OR SOLID

Element	Physical State	g/cm³	°C*	Authority
Iridium		22.42	17	Deville-Debray
Iodine		4.940	20	Richards-Stull
"	liquid	3.71	184	Drugman, Ramsey
Iron	pure	7.86		Bureau of Standards
"	gray cast	7.03–7.13		
"	white cast	7.58–7.73		
"	wrought	7.80–7.90		
"	liquid	6.88		Roberts-Austen
"	"	6.91	1200	Honda
Krypton	"	2.16	−146	Ramsay-Travers
"	solid	3.4	−273	Computed†
Lanthanum		6.15		Muthmann-Weiss
Lead	vacuo-distilled	11.342	20	Kahlbaum, 1902
"	ditto-compressed	11.347	20	" "
"	solid	11.005	325	Vincentini-Omodei
"	liquid	10.597	400	Day, Sosman, Hostetter,
"	"	10.078	850	1914
Lithium		0.534	20	Richards-Brink, 1907
Magnesium		1.741		Voigt
Manganese		7.3		Mean
Mercury	liquid	13.596	0	Thiesen, Scheel, Sell,
"	"	13.546	20	Heuse, 1912
"	"	13.690	− 38.8	Vincentini-Omodei
"	solid	14.193	− 38.8	Mallet
"	"	14.383	−188	Dewar, 1902
Molybdenum		10.2		Davy, 1925
Neodymium		7.00		Kremers, 1925
Neon		1.204	−245	Onnes, Alii
Nickel		8.8		
Nitrogen	liquid	0.810	−195	Baly-Donnan, 1902
"	"	0.854	−205	" " "
"	solid	1.0265	−252.5	Dewar
"	"	1.14	−273	Computed†
Osmium		22.5		Deville-Debray
Oxygen	liquid	1.132	−183.6	Drugman, Ramsey
"	solid	1.426	−252.5	Dewar
"	"	1.568	−273	Computed†
Palladium		11.5		
Phosphorus	white	1.83		
"	red	2.20		
"	metallic	2.34	15	Hittorf
"	black	2.69		Bridgman, 1918
Platinum		21.37	20	Richards-Stull
"	black	2.70		
Potassium		0.870	20	Richards-Brink, 1907
"	solid	0.851	62.1	Vincentini-Omodei
"	liquid	0.830	62.1	" "
Praseodymium		6.6	25	Wierda, Kremers, 1925
Rhodium		12.44		Holborn Henning
Rubidium		1.532	20	Richards-Brink, 1907
Ruthenium		12.30	19	Ruff, Vidic, 1925
Samarium		7.7–7.8		Muthmann-Weiss
Selenium		4.82		Bradley, 1924
Silicon	cryst.	2.42	20	Richards-Stull-Brink
"	amorph.	2.35	15	Vigoroux
Silver	cast	10.42–10.53		
"	vacuo-distilled	10.492	20	Kahlbaum, 1902
"	" -compressed	10.503	20	" "
"	liquid	9.51		Wrightson
Sodium		0.9712	20	Richards-Brink, 1907
"	solid	0.9519	97.6	Vincentini-Omodei
"	liquid	0.9287	97.6	" "
"		1.0066	−188	Dewar

* Where the temperature is not given, ordinary temperature is understood. † Herz, 1919.

TABLE 112 (*concluded*).—Density of the elements, liquid or solid

Element	Physical state	g/cm³	°C*	Authority
Strontium	solid	2.60		
Sulphur	"	2.0–2.1		
"	liquid	1.811	113	Vincentini-Omodei
Tantalum		16.6		
Tellurium	crystallized	6.25		
"	amorphous	6.02	20	Bjeljankin
Thallium		11.86		Stull
Thorium		11.00	17	Nilson
Tin	white, cast	7.29		Matthiessen
"	" wrought	7.30		
"	" solid	7.184	226	Vincentini-Omodei
"	liquid	6.99	226	" "
"	gray	5.8		
Titanium		4.5	18	Mixter
Tungsten		18.6–19.1		
Uranium		18.7	13	Zimmermann
Vanadium		5.6		
Xenon	liquid	3.52	109	Ramsay-Travers
Yttrium		4.57		Kremers, 1926
Zinc	cast	7.04–7.16		
"	solid	4.32	−273	Herz, computed
"	vacuo-distilled	6.92	20	Kahlbaum, 1902
"	ditto-compressed	7.13	20	" "
"	liquid	6.48		Roberts-Wrightson
Zirconium		6.53		De Boer, 1930

TABLE 113.—Density in grams per cubic centimeter and in pounds per cubic foot of different kinds of wood

Wood is to be seasoned and of average dryness. See also pages 132 to 135 and 163

Wood	Grams per cubic centimeter	Pounds per cubic foot	Wood	Grams per cubic centimeter	Pounds per cubic foot
Alder	0.42–0.68	26–42	Greenheart	0.93–1.04	58–65
Apple	0.66–0.84	41–52	Hazel	0.60–0.80	37–49
Ash	0.65–0.85	40–53	Hickory	0.60–0.93	37–58
Balsa	<Cork		Holly	0.76	47
Bamboo	0.31–0.40	19–25	Iron-bark	1.03	64
Basswood.			Juniper	0.56	35
See Linden			Laburnum	0.92	57
Beech	0.70–0.90	43–56	Lancewood	0.68–1.00	42–62
Blue gum	1.00	62	Lignum vitæ	1.17–1.33	73–83
Birch	0.51–0.77	32–48	Linden or Lime-tree	0.32–0.59	20–37
Box	0.95–1.16	59–72	Locust	0.67–0.71	42–44
Bullet-tree	1.05	65	Logwood	0.91	57
Butternut	0.38	24	Mahogany, Honduras	0.66	41
Cedar	0.49–0.57	30–35	" Spanish	0.85	53
Cherry	0.70–0.90	43–56	Maple	0.62–0.75	39–47
Cork	0.22–0.26	14–16	Oak	0.60–0.90	37–56
Dogwood	0.76	47	Pear-tree	0.61–0.73	38–45
Ebony	1.11–1.33	69–83	Plum-tree	0.66–0.78	41–49
Elm	0.54–0.60	34–37	Poplar	0.35–0.5	22–31
Pine, Eastern White	0.35–0.50	22–31	Satinwood	0.95	59
" Larch	0.50–0.56	31–35	Sycamore	0.40–0.60	24–37
" Pitch	0.83–0.85	52–53	Teak, Indian	0.66–0.88	41–55
" Red	0.48–0.70	30–44	" African	0.98	61
" Scotch	0.43–0.53	27–33	Walnut	0.64–0.70	40–43
" Spruce	0.48–0.70	30–44	Water gum	1.00	62
" Yellow	0.37–0.60	23–37	Willow	0.40–0.60	24–37

* Where the temperature is not given, ordinary atmospheric temperature is understood.

DENSITY IN GRAMS PER CUBIC CENTIMETER AND POUNDS PER CUBIC FOOT OF VARIOUS SOLIDS

N. B. The density of a specimen depends considerably on its state and previous treatment; especially is this the case with porous materials.

Material.	Grams per cu. cm.	Pounds per cu. foot.	Material.	Grams per cu. cm.	Pounds per cu. foot.
Agate	2.5–2.7	156–168	Gum arabic	1.3–1.4	80– 85
Alabaster:			Gypsum	2.31–2.33	144–145
Carbonate	2.69–2.78	168–173	Hematite	4.9–5.3	306–330
Sulphate	2.26–2.32	141–145	Hornblende	3.0	187
Albite	2.62–2.65	163–165	Ice	0.917	57.2
Amber	1.06–1.11	66– 69	Ilmenite	4.5–5.	280–310
Amphiboles	2.9–3.2	180–200	Ivory	1.83–1.92	114–120
Anorthite	2.74–2.76	171–172	Labradorite	2.7–2.72	168–170
Anthracite	1.4–1.8	87–112	Lava: basaltic	2.8–3.0	175–185
Asbestos	2.0–2.8	125–175	trachytic	2.0–2.7	125–168
Asphalt	1.1–1.5	69– 94	Leather: dry	0.86	54
Basalt	2.4–3.1	150–190	greased	1.02	64
Beeswax	0.96–0.97	60– 61	Lime: mortar	1.65–1.78	103–111
Beryl	2.69–2.7	168–168	slaked	1.3–1.4	81– 87
Biotite	2.7–3.1	170–190	Limestone	2.68–2.76	167–171
Bone	1.7–2.0	106–125	Litharge:		
Brick	1.4–2.2	87–137	Artificial	9.3–9.4	580–585
Butter	0.86–0.87	53– 54	Natural	7.8–8.0	490–500
Calamine	4.1–4.5	255–280	Magnetite	4.9–5.2	306–324
Caoutchouc	0.92–0.99	57– 62	Malachite	3.7–4.1	231–256
Celluloid	1.4	87	Marble	2.6–2.84	160–177
Cement, set	2.7–3.0	170–190	Meerschaum	0.99–1.28	62– 80
Chalk	1.9–2.8	118–175	Mica	2.6–3.2	165–200
Charcoal: oak	0.57	35	Muscovite	2.76–3.00	172–225
pine	0.28–0.44	18– 28	Ochre	3.5	218
Chrome yellow	6.00	374	Oligoclase	2.65–2.67	165–167
Chromite	4.32–4.57	270–285	Olivine	3.27–3.37	204–210
Cinnabar	8.12	507	Opal	2.2	137
Clay	1.8–2.6	122–162	Orthoclase	2.58–2.61	161–163
Coal, soft	1.2–1.5	75– 94	Paper	0.7–1.15	44– 72
Cocoa butter	0.89–0.91	56– 57	Paraffin	0.87–0.91	54– 57
Coke	1.0–1.7	62–105	Peat	0.84	52
Copal	1.04–1.14	65– 71	Pitch	1.07	67
Corundum	3.9–4.0	245–250	Porcelain	2.3–2.5	143–156
Diamond:			Porphyry	2.6–2.9	162–181
Anthracitic	1.66	104	Pyrite	4.95–5.1	309–318
Carbonado	3.01–3.25	188–203	Quartz	2.65	165
Diorite	2.52	157	Quartzite	2.73	170
Dolomite	2.84	177	Resin	1.07	67
Ebonite	1.15	72	Rock salt	2.18	136
Emery	4.0	250	Rutile	4.2	260
Epidote	3.25–3.5	203–218	Sandstone	2.14–2.36	134–147
Feldspar	2.55–2.75	159–172	Serpentine	2.50–2.65	156–165
Flint	2.63	164	Slag, furnace	2.0–3.9	125–240
Fluorite	3.18	198	Slate	2.6–3.3	162–205
Gamboge	1.2	75	Soapstone	2.6–2.8	162–175
Garnet	3.15–4.3	197–268	Starch	1.53	95
Gas carbon	1.88	117	Sugar	1.61	100
Gelatine	1.27	180	Talc	2.7–2.8	168–174
Glass: common	2.4–2.8	150–175	Tallow	0.91–0.97	57– 60
flint	2.9–5.9	180–370	Topaz	3.5–3.6	219–223
Glue	1.27	80	Tourmaline	3.0–3.2	190–200
Granite	2.64–2.76	165–172	Zircon	4.68–4.70	292–293
Graphite	2.30–2.72	144–170			

TABLE 115.—Density in Grams per Cubic Centimeter and Pounds per Cubic Foot of Various Alloys

Alloy	Grams per cubic centimeter	Pounds per cubic foot
Brasses: Yellow, 70Cu + 30Zn, cast	8.44	527
" " " rolled	8.56	534
" " " drawn	8.70	542
" Red, 90Cu + 10Zn	8.60	536
" White, 50Cu + 50Zn	8.20	511
Bronzes: 90Cu + 10Sn	8.78	548
" 85Cu + 15Sn	8.89	555
" 80Cu + 20Sn	8.74	545
" 75Cu + 25Sn	8.83	551
German Silver: Chinese, 26.3Cu + 36.6Zn + 36.8Ni	8.30	518
" " Berlin (1) 52Cu + 26Zn + 22Ni	8.45	527
" " " (2) 59Cu + 30Zn + 11Ni	8.34	520
" " " (3) 63Cu + 30Zn + 6Ni	8.30	518
" " Nickelin	8.77	547
Lead and Tin: 87.5Pb + 12.5Sn	10.60	661
" " " 84Pb + 16Sn	10.33	644
" " " 77.8Pb + 22.2Sn	10.05	627
" " " 63.7Pb + 36.3Sn	9.43	588
" " " 46.7Pb + 53.3Sn	8.73	545
" " " 30.5Pb + 69.5Sn	8.24	514
Bismuth, Lead, and Cadmium: 53Bi + 40Pb + 7Cd	10.56	659
Wood's Metal: 50Bi + 25Pb + 12.5Cd + 12.5Sn	9.70	605
Cadmium and Tin: 32Cd + 68Sn	7.70	480
Gold and Copper: 98Au + 2Cu	18.84	1176
" " " 96Au + 4Cu	18.36	1145
" " " 94Au + 6Cu	17.95	1120
" " " 90Au + 10Cu	17.16	1071
" " " 86Au + 14Cu	16.47	1027
Aluminum and Copper: 10Al + 90Cu	7.69	480
" " " 5Al + 95Cu	8.37	522
" " " 3Al + 97Cu	8.69	542
Aluminum and Zinc: 91Al + 9Zn	2.80	175
Platinum and Iridium: 90Pt + 10Ir	21.62	1348
" " " 85Pt + 15Ir	21.62	1348
" " " 66.67Pt + 33.33Ir	21.87	1364
Carboloy	14.3	895
Constantan: 60Cu + 40Ni	8.88	554
Magnalium: 70Al + 30Mg	2.0	125
Manganin: 84Cu + 12Mn + 4Ni	8.5	530
Monel metal	8.87	554
Platinoid: German silver + little Tungsten	9.0	560
Stellite: Co 59.5; Mo 22.5; Cr 10.8; Fe 3.1; Mn 2.0; C 0.9; Si 0.8	8.3	518

TABLE 116.—Density (g/cm³) of some foreign woods on the American market

(See also pages 132-135 and 161.)

Almon	0.464	Gardner	Olive	0.94	Boulger
Bullet-wood, Guiana	1.03–1.23	Boulger	Orange Wood	.70	"
Boxwood, West Indian	.83– .88	"	Padouk	.89–1.29	"
Balsa	.11	Carpenter	Prima Vera	.58	Howard
Carreto	.84	U.S.F.P.L.	Purple-heart	.72– .97	Boulger
Cedar, Spanish	.38	"	Quebracho	1.25	"
Cocobola	1.20	Boulger	Rosewood, Brazil	.77– .84	"
Cocus	1.25	Stone	Rosewood, Honduras	1.09–1.23	"
Fustic	.68	Boulger	Sabicu	.90– .96	"
Koa	.83	Howard	Snakewood	1.05–1.33	"
Lauaan, Red	.41	Gardner	Tamarind	1.32	"
Mahogany, African	.55	Boulger	Tanguile	.47– .51	Gardner
Mahogany, E. Indian	.38	"	Wallaba	.93– .94	Boulger
Mora	1.07–1.09	"	Zebra Wood	1.03	"
Oak, English	.60– .78	"			

Table prepared by W. M. N. Watkins, U. S. National Museum

TABLE 117

DENSITY OF VARIOUS NATURAL AND ARTIFICIAL MINERALS

Name and formula	C	Density in grams per cm³	Sp. vol. in cm³ per gram	Reference
Oxides				
Corundum Al_2O_3 art	(0°)	3.980	.2513	11, 14[a]
Lime CaO art	(25°)	3.306	.3025	2
Magnesia MgO art	(25°)	3.603	.2775	5, 13[a]
Ferrous oxide FeO art	(20°)	5.99	.1669	15[a]
Hematite Fe_2O_3	(20°)	5.25	.1905	14[a]
Magnetite Fe_3O_4	(0°)	5.172	.1933	11
Quartz SiO_2 nat	(20°)	2.649	.3775	22
" " art	(25°)	2.648	.3776	22
Cristobalite SiO_2 art	(25°)	2.325	.4301	22
Vitreous silica	(0°)	2.203	.4539	22
Rutile TiO_2	(0°)	4.250	.2353	11
Ilmenite $(FeTi)_2O_3$	(0°)	5.088	.1965	11
Silicates				
Sillimanite $Al_2O_3.SiO_2$	(25°)	3.247	.3080	16
Mullite $3Al_2O_3.2SiO_2$ art	(25°)	3.156	.3169	16
Albite $NaAlSi_3O_8$ art	(25°)	2.597	.3851	1
Anorthite $CaAl_2Si_2O_8$ art	(25°)	2.757	.3627	1
Nephelite $NaAlSiO_4$ art	(21°)	2.619	.3818	6
Labradorite $Ab_{48}An_{52}$	(26°)	2.695	.3711	12
Oligoclase $Ab_{78}An_{22}$	(25°)	2.638	.3791	12
Orthoclase $KAlSi_3O_8$[b]	(15°)	2.554	.3915	20
" adularia	(15°)	2.566	.3897	20
Microcline	(25°)	2.557	.3911	12
Calcium Orthosilicates				
α — Ca_2SiO_4 art	(25°)	3.26	.307	2
β — Ca_2SiO_4 art	(25°)	3.27	.306	2
γ — Ca_2SiO_4 art	(25°)	2.965	.3373	2
Calcium Metasilicates				
α — $CaSiO_3$ (ψ — Wollastonite) art	(25°)	2.904	.3444	2
β — $CaSiO_3$ (Wollastonite) art	(25°)	2.906	.3441	2
Diopside $CaSiO_3.MgSiO_3$	(28°)	3.257	.3070	12
" " art	(25°)	3.265	.3063	4
Enstatite $MgSiO_3$ art	(25°)	3.166	.3159	3
" $(MgSiO_3)_{88}$ $(FeSiO_3)_{12}$	(25°)	3.254	.3073	12
Hypersthene $(MgSiO_3)_{70}$ $(FeSiO_3)_{30}$	(29°)	3.415	.2928	12
Forsterite Mg_2SiO_4	(20°)	3.223	.3103	17
Fayalite Fe_2SiO_4 art	(15°)	4.28	.234	10
Garnet—grossularite	(31°)	3.544	.2822	18
" almandite	(31°)	4.160	.2404	18
Jadeite	(31°)	3.328	.3005	18
Miscellaneous Substances				
Borax, Anhydrous, $Na_2B_4O_7$ art		2.27	.440	1
$CaCO_3$; aragonite	(0°)	2.932	.3411	11
$CaCO_3$; calcite	(20°)	2.7102	.3688	21
CaF_2; fluorite	(10°)	3.180	.3145	8
Diamond	(25°)	3.516	.2844	12
NaCl; rock salt	(20°)	2.1632	.4623	21
Na_2SO_4V; thenardite art	(25°)	2.664	.3754	19
Na_2SO_4III art	(25°)	2.697	.3708	19
KCl; fine powder art	(30°)	1.984	.5040	7
Pyrite FeS_2	(25°)	5.012	.1995	9
Marcasite FeS_2	(25°)	4.873	.2052	9

(1) Day and Allen, 1905. (2) Day and Shepherd, 1906. (3) Allen, Wright and Clement, 1906. (4) Allen and White, 1909. (5) Larsen, 1909. (6) Bowen, 1912. (7) Johnston and Adams, 1911. (8) Merwin, 1911. (9) Allen and Crenshaw, 1911. (10) Busz and Rüsberg, 1913. (11) Madelung and Fuchs, 1921. (12) Adams and Williamson, 1923. (13) Rinne, 1923. (14) Pauling and Hendricks, 1925. (15) Wyckoff and Crittenden, 1925. (16) Greig (unpublished). (17) Aurousseau and Merwin, 1928. (18) Adams and Gibson, 1929. (19) Kracek and Gibson, 1929. (20) Bjeljankin, 1927. (21) DeFoe and Compton, 1925. (22) Sosman, 1927.

[a] X-ray diffraction data.
[b] Calculated from density and composition of adularia.

DENSITY OF LIQUIDS

Density or mass in grams per cubic centimeter and in pounds per cubic foot of various liquids.

Liquid.	Grams per cubic centimeter.	Pounds per cubic foot.	Temp. C.
Acetone	0.792	49.4	20°
Alcohol, ethyl	0.807	50.4	0
" methyl	0.810	50.5	0
Aniline	1.035	64.5	0
Benzene	0.899	56.1	0
Bromine	3.187	199.0	0
Carbolic acid (crude)	0.950–0.965	59.2–60.2	15
Carbon disulphide	1.293	80.6	0
Chloroform	1.489	93.0	20
Cocoa-butter	0.857	53.5	100
Ether	0.736	45.9	0
Gasoline	0.66–0.69	41.0–43.0	–
Glycerine	1.260	78.6	0
Japan wax	0.875	54.6	100
Milk	1.028–1.035	64.2–64.6	–
Naphtha (wood)	0.848–0.810	52.9–50.5	0
Naphtha (petroleum ether)	0.665	41.5	15
Oils: Amber	0.800	49.9	15
Anise-seed	0.996	62.1	16
Camphor	0.910	56.8	–
Castor	0.969	60.5	15
Clove	1.04–1.06	65.–66.	25
Cocoanut	0.925	57.7	15
Cotton Seed	0.926	57.8	16
Creosote	1.040–1.100	64.9–68.6	15
Lard	0.920	57.4	15
Lavender	0.877	54.7	16
Lemon	0.844	52.7	16
Linseed (boiled)	0.942	58.8	15
Neat's foot	0.913–.917	57.0–57.2	–
Olive	0.918	57.3	15
Palm	0.905	56.5	15
Pentane	0.650	40.6	0
"	0.623	38.9	25
Peppermint	0.90–.92	56–57	25
Petroleum	0.878	54.8	0
" (light)	0.795–0.805	49.6–50.2	15
Pine	0.850–0.860	53.0–54.0	15
Poppy	0.924	57.7	–
Rapeseed (crude)	0.915	57.1	15
" (refined)	0.913	57.0	15
Resin	0.955	59.6	15
Sperm	0.88	55.	25
Soya-bean	0.919	57.3	30
" "	0.906	56.5	90
Train or Whale	0.918–0.925	57.3–57.7	15
Turpentine	0.873	54.2	16
Valerian	0.965	60.2	16
Wintergreen	1.18	74.	25
Pyroligneous acid	0.800	49.9	0
Water	1.000	62.4	4

DENSITY OF PURE WATER FREE FROM AIR. 0° TO 41° C

[Under standard pressure (76 cm), at every tenth part of a degree of the international hydrogen scale from 0° to 41° C, in grams per milliliter[1]]

Degrees Centigrade.	Tenths of Degrees. 0	1	2	3	4	5	6	7	8	9	Mean Differences.
0	0.999 8681	8747	8812	8875	8936	8996	9053	9109	9163	9216	+ 59
1	9267	9315	9363	9408	9452	9494	9534	9573	9610	9645	+ 41
2	9679	9711	9741	9769	9796	9821	9844	9866	9887	9905	+ 24
3	9922	9937	9951	9962	9973	9981	9988	9994	9998	*0000	+ 8
4	1.000 0000	*9999	*9996	*9992	*9986	*9979	*9970	*9960	*9947	*9934	— 8
5	0.999 9919	9902	9884	9864	9842	9819	9795	9769	9742	9713	— 24
6	9682	9650	9617	9582	9545	9507	9468	9427	9385	9341	— 39
7	9296	9249	9201	9151	9100	9048	8994	8938	8881	8823	— 53
8	8764	8703	8641	8577	8512	8445	8377	8308	8237	8165	— 67
9	8091	8017	7940	7863	7784	7704	7622	7539	7455	7369	— 81
10	7282	7194	7105	7014	6921	6826	6729	6632	6533	6432	— 95
11	6331	6228	6124	6020	5913	5805	5696	5586	5474	5362	—108
12	5248	5132	5016	4898	4780	4660	4538	4415	4291	4166	—121
13	4040	3912	3784	3654	3523	3391	3257	3122	2986	2850	—133
14	2712	2572	2431	2289	2147	2003	1858	1711	1564	1416	—145
15	1266	1114	0962	0809	0655	0499	0343	0185	0026	*9865	—156
16	0.998 9705	9542	9378	9214	9048	8881	8713	8544	8373	8202	—168
17	8029	7856	7681	7505	7328	7150	6971	6791	6610	6427	—178
18	6244	6058	5873	5686	5498	5309	5119	4927	4735	4541	—190
19	4347	4152	3955	3757	3558	3358	3158	2955	2752	2549	—200
20	2343	2137	1930	1722	1511	1301	1090	0878	0663	0449	—211
21	0233	0016	*9799	*9580	*9359	*9139	*8917	*8694	*8470	*8245	—221
22	0.997 8019	7792	7564	7335	7104	6873	6641	6408	6173	5938	—232
23	5702	5466	5227	4988	4747	4506	4264	4021	3777	3531	—242
24	3286	3039	2790	2541	2291	2040	1788	1535	1280	1026	—252
25	0770	0513	0255	*9997	*9736	*9476	*9214	*8951	*8688	*8423	—261
26	0.996 8158	7892	7624	7356	7087	6817	6545	6273	6000	5726	—271
27	5451	5176	4898	4620	4342	4062	3782	3500	3218	2935	—280
28	2652	2366	2080	1793	1505	1217	0928	0637	0346	0053	—289
29	0.995 9761	9466	9171	8876	8579	8282	7983	7684	7383	7083	—298
30	6780	6478	6174	5869	5564	5258	4950	4642	4334	4024	—307
31	3714	3401	3089	2776	2462	2147	1832	1515	1198	0880	—315
32	0561	0241	*9920	*9599	*9276	*8954	*8630	*8304	*7979	*7653	—324
33	0.994 7325	6997	6668	6338	6007	5676	5345	5011	4678	4343	—332
34	4007	3671	3335	2997	2659	2318	1978	1638	1296	0953	—340
35	0610	0267	*9922	*9576	*9230	*8883	*8534	*8186	*7837	*7486	—347
36	0.993 7136	6784	6432	6078	5725	5369	5014	4658	4301	3943	—355
37	3585	3226	2866	2505	2144	1782	1419	1055	0691	0326	—362
38	0.992 9960	9593	9227	8859	8490	8120	7751	7380	7008	6636	—370
39	6263	5890	5516	5140	4765	4389	4011	3634	3255	2876	—377
40	2497	2116	1734	1352	0971	0587	0203	*9818	*9433	*9047	—384
41	0.991 8661										

[1] According to P. Chappuis, Bureau international des Poids et Mesures, Travaux et Mémoires, 13; 1907.

VOLUME IN CUBIC CENTIMETERS AT VARIOUS TEMPERATURES OF A CUBIC CENTIMETER OF WATER FREE FROM AIR AT THE TEMPERATURE OF MAXIMUM DENSITY. 0° TO 36° C

Hydrogen Thermometer Scale

Temp. C.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	1.000132	125	118	112	106	100	095	089	084	079
1	073	069	064	059	055	051	047	043	039	035
2	032	029	026	023	020	018	016	013	011	009
3	008	006	005	004	003	002	001	001	000	000
4	000	000	000	001	001	002	003	004	005	007
5	008	010	012	014	016	018	021	023	026	029
6	032	035	039	042	046	050	054	058	062	066
7	070	075	080	085	090	095	101	106	112	118
8	124	130	137	142	149	156	162	169	176	184
9	191	198	206	214	222	230	238	246	254	263
10	272	281	290	299	308	317	327	337	347	357
11	367	377	388	398	409	420	430	441	453	464
12	476	487	499	511	522	534	547	559	571	584
13	596	609	623	636	649	661	675	688	702	715
14	729	743	757	772	786	800	815	830	844	859
15	873	890	905	920	935	951	967	983	998	015*
16	1.001031	047	063	080	097	113	130	147	164	182
17	198	216	233	252	269	287	305	323	341	358
18	378	396	415	433	452	471	490	510	529	548
19	568	588	606	626	646	667	687	707	728	748
20	769	790	811	832	853	874	895	916	938	960
21	981	002*	024*	046*	068*	091*	113*	135*	158*	181*
22	1.002203	226	249	271	295	319	342	364	389	412
23	436	459	483	507	532	556	581	605	629	654
24	679	704	729	754	779	804	829	854	879	905
25	932	958	983	010*	036*	061*	088*	115*	141*	168*
26	1.003195	221	248	275	302	330	357	384	412	439
27	467	495	523	550	579	607	635	663	692	720
28	749	776	806	836	865	893	922	951	981	011*
29	1.004041	069	100	129	160	189	220	250	280	310
30	341	371	403	432	464	494	526	557	588	619
31	651	682	713	744	777	808	840	872	904	936
32	968	001*	033*	066*	098*	132*	163*	197*	229*	263*
33	1.005296	328	361	395	427	461	496	530	562	597
34	631	665	698	732	768	802	836	871	904	940
35	975	009*	044*	078*	115*	150*	185*	219*	255*	290*

Reciprocals of the preceding table.

Influence of Pressure *

kg/cm²	0° C	20° C	40° C	kg/cm²	20° C	40° C
1	1.0000	1.0016	1.0076	7,000	0.8404	0.8485
500	.9771	.9808	.9873	8,000	.8275	.8360
1,000	.9578	.9630	.9700	9,000	.8160	.8249
2,000	.9260	.9327	.9403	10,000	—	.8149
3,000	.9015	.9087	.9164	11,000	—	.8056
5,000	.8632	.8702	.8778	12,000	—	.7966
6,000	.8480	.8545	.8623	12,500	—	.7922

* Williamson, Change of Physical Properties with Pressure, J. Frank. Inst. 193, p. 491, 1922.

TABLE 121

DENSITY AND VOLUME OF WATER
—10° TO +250° C

The mass of one cubic centimeter at 4° C is taken as unity.

Temp. C.	Density.	Volume.	Temp. C.	Density.	Volume.
—10°	0.99815	1.00186	**+35°**	0.99406	1.00598
—9	843	157	36	371	633
—8	869	131	37	336	669
—7	892	108	38	300	706
—6	912	088	39	263	743
5	0.99930	1.00070	**40**	0.99225	1.00782
—4	945	055	41	187	821
—3	958	042	42	147	861
—2	970	031	43	107	901
—1	979	021	44	066	943
+0	0.99987	1.00013	**45**	0.99025	1.00985
1	993	007	46	0.98982	1.01028
2	997	003	47	940	072
3	999	001	48	896	116
4	1.00000	1.00000	49	852	162
5	0.99999	1.00001	**50**	0.98807	1.01207
6	997	003	51	762	254
7	993	007	52	715	301
8	988	012	53	669	349
9	981	019	54	621	398
10	0.99973	1.00027	**55**	0.98573	1.01448
11	963	037	60	324	705
12	952	048	65	059	979
13	940	060	70	0.97781	1.02270
14	927	073	75	489	576
15	0.99913	1.00087	**80**	0.97183	1.02899
16	897	103	85	0.96865	1.03237
17	880	120	90	534	590
18	862	138	95	192	959
19	843	157	100	0.95838	1.04343
20	0.99823	1.00177	**110**	0.9510	1.0515
21	802	198	120	.9434	1.0601
22	780	220	130	.9352	1.0693
23	757	244	140	.9264	1.0794
24	733	268	150	.9173	1.0902
25	0.99708	1.00293	**160**	0.9075	1.1019
26	682	320	170	.8973	1.1145
27	655	347	180	.8866	1.1279
28	627	375	190	.8750	1.1429
29	598	404	200	.8628	1.1590
30	0.99568	1.00434	**210**	0.850	1.177
31	537	465	220	.837	1.195
32	506	497	230	.823	1.215
33	473	530	240	.809	1.236
34	440	563	250	.794	1.259

From — 10° to 0° the values are due to means from Pierre, Weidner, and Rosetti; from 0° to 41°, to Chappuis, 42° to 100°, to Thiesen; 110° to 250°, to means from the works of Ramsey, Young, Waterston, and Hirn.

TABLE 122

DENSITY AND VOLUME OF MERCURY

– 10° to + 360°C

Density or mass in grams per cubic centimeter, and the volume in cubic centimeters of one gram of mercury.

Temp. C.	Mass in grams per cu. cm.	Volume of 1 gram in cu. cms.	Temp. C.	Mass in grams per cu. cm.	Volume of 1 gram in cu. cms.
–10°	13.6198	0.0734225	**30°**	13.5213	0.0739572
–9	6173	4358	31	5189	9705
–8	6148	4492	32	5164	9839
–7	6124	4626	33	5140	9973
–6	6099	4759	34	5116	40107
–5	13.6074	0.0734893	**35**	13.5091	0.0740241
–4	6050	5026	36	5066	0374
–3	6025	5160	37	5042	0508
–2	6000	5293	38	5018	0642
–1	5976	5427	39	4994	0776
–0	13.5951	0.0735560	**40**	13.4969	0.0740910
1	5926	5694	50	4725	2250
2	5901	5828	60	4482	3592
3	5877	5961	70	4240	4936
4	5852	6095	80	3998	6282
5	13.5827	0.0736228	**90**	13.3723	0.0747631
6	5803	6362	100	3515	8981
7	5778	6496	110	3279	50305
8	5754	6629	120	3040	1653
9	5729	6763	130	2801	3002
10	13.5704	0.0736893	**140**	13.2563	0.0754[illegible]54
11	5680	7030	150	2326	5708
12	5655	7164	160	2090	7064
13	5630	7298	170	1853	8422
14	5606	7431	180	1617	9784
15	13.5581	0.0737565	**190**	13.1381	0.0761149
16	5557	7699	200	1145	2516
17	5532	7832	210	0910	3886
18	5507	7966	220	0677	5260
19	5483	8100	230	0440	6637
20	13.5458	0.0738233	**240**	13.0206	0.0768017
21	5434	8367	250	12.9972	9402
22	5409	8501	260	9738	7090
23	5385	8635	270	9504	2182
24	5360	8768	280	9270	3579
25	13.5336	0.0738902	**290**	12.9036	0.0774979
26	5311	9036	300	8803	6385
27	5287	9170	310	8569	7795
28	5262	9304	320	8336	9210
29	5238	9437	330	8102	80630
30	13.5213	0.0739571	**340**	12.7869	0.0782054
			350	7635	3485
			360	7402	4921

Based upon Thiesen und Scheel, Tätigkeitber. Phys.-Techn. Reichsanstalt, 1897-1898; Chappuis, Trav. Bur. Int. 13, 1903. Thiesen, Scheel, Sell; Wiss. Abh. Phys.-Techn. Reichsanstalt 2, p. 184, 1895, and 1 liter = 1.000027 cu. dm.

Table 123

DENSITY OF AQUEOUS SOLUTIONS *

The following table gives the density of solutions of various salts in water. The numbers give the weight in grams per cubic centimeter. For brevity the substance is indicated by formula only.

Substance.	Weight of the dissolved substance in 100 parts by weight of the solution.									Temp. C.	Authority.
	5	10	15	20	25	30	40	50	60		
K_2O	1.047	1.098	1.153	1.214	1.284	1.354	1.503	1.659	1.809	15.	Schiff.
KOH . . .	1.040	1.082	1.127	1.176	1.229	1.286	1.410	1.538	1.666	15.	"
Na_2O . . .	1.073	1.144	1.218	1.284	1.354	1.421	1.557	1.689	1.829	15.	"
$NaOH$ . . .	1.058	1.114	1.169	1.224	1.279	1.331	1.436	1.539	1.642	15.	"
NH_3	0.978	0.959	0.940	0.924	0.909	0.896	–	–	–	16.	Carius.
NH_4Cl . . .	1.015	1.030	1.044	1.058	1.072	–	–	–	–	15.	Gerlach.
KCl	1.031	1.065	1.099	1.135	–	–	–	–	–	15.	"
$NaCl$	1.035	1.072	1.110	1.150	1.191	–	–	–	–	15.	"
$LiCl$	1.029	1.057	1.085	1.116	1.147	1.181	1.255	–	–	15.	"
$CaCl_2$ . . .	1.041	1.086	1.132	1.181	1.232	1.286	1.402	–	–	15.	"
$CaCl_2 + 6H_2O$	1.019	1.040	1.061	1.083	1.105	1.128	1.176	1.225	1.276	18.	Schiff.
$AlCl_3$ . . .	1.030	1.072	1.111	1.153	1.196	1.241	1.340	–	–	15.	Gerlach.
$MgCl_2$ . . .	1.041	1.085	1.130	1.177	1.226	1.278	–	–	–	15.	"
$MgCl_2+6H_2O$	1.014	1.032	1.049	1.067	1.085	1.103	1.141	1.183	1.222	24.	Schiff.
$ZnCl_2$ . . .	1.043	1.089	1.135	1.184	1.236	1.289	1.417	1.563	1.737	19.5	Kremers.
$CdCl_2$ . . .	1.043	1.087	1.138	1.193	1.254	1.319	1.469	1.653	1.887	19.5	"
$SrCl_2$	1.044	1.092	1.143	1.198	1.257	1.321	–	–	–	15.	Gerlach.
$SrCl_2 + 6H_2O$	1.027	1.053	1.082	1.111	1.042	1.174	1.242	1.317	–	15.	"
$BaCl_2$ . . .	1.045	1.094	1.147	1.205	1.269	–	–	–	–	15.	"
$BaCl_2 + 2H_2O$	1.035	1.075	1.119	1.166	1.217	1.273	–	–	–	21.	Schiff.
$CuCl_2$ . . .	1.044	1.091	1.155	1.221	1.291	1.360	1.527	–	–	17.5	Franz.
$NiCl_2$ . . .	1.048	1.098	1.157	1.223	1.299	–	–	–	–	17.5	"
$HgCl_2$ . . .	1.041	1.092	–	–	–	–	–	–	–	20.	Mendelejeff.
Fe_2Cl_6 . . .	1.041	1.086	1.130	1.179	1.232	1.290	1.413	1.545	1.668	17.5	Hager.
$PtCl_4$	1.046	1.097	1.153	1.214	1.285	1.362	1.546	1.785	–	–	Precht.
$SnCl_2 + 2H_2O$	1.032	1.067	1.104	1.143	1.185	1.229	1.329	1.444	1.580	15.	Gerlach.
$SnCl_4 + 5H_2O$	1.029	1.058	1.089	1.122	1.157	1.193	1.274	1.365	1.467	15.	"
$LiBr$	1.033	1.070	1.111	1.154	1.202	1.252	1.366	1.498	–	19.5	Kremers.
KBr	1.035	1.073	1.114	1.157	1.205	1.254	1.364	–	–	19.5	"
$NaBr$ . . .	1.038	1.078	1.123	1.172	1.224	1.279	1.408	1.563	–	19.5	"
$MgBr_2$ . . .	1.041	1.085	1.135	1.189	1.245	1.308	1.449	1.623	–	19.5	"
$ZnBr_2$ . . .	1.043	1.091	1.144	1.202	1.263	1.328	1.473	1.648	1.873	19.5	"
$CdBr_2$ . . .	1.041	1.088	1.139	1.197	1.258	1.324	1.479	1.678	–	19.5	"
$CaBr_2$ . . .	1.042	1.087	1.137	1.192	2.250	1.313	1.459	1.639	–	19.5	"
$BaBr_2$ . . .	1.043	1.090	1.142	1.199	1.260	1.327	1.483	1.683	–	19.5	"
$SrBr_2$ . . .	1.043	1.089	1.140	1.198	1.260	1.328	1.489	1.693	1.953	19.5	"
KI	1.036	1.076	1.118	1.164	1.216	1.269	1.394	1.544	1.732	19.5	"
LiI	1.036	1.077	1.122	1.170	1.222	1.278	1.412	1.573	1.775	19.5	"
NaI	1.038	1.080	1.126	1.177	1.232	1.292	1.430	1.598	1.808	19.5	"
ZnI_2 . . .	1.043	1.089	1.138	1.194	1.253	1.316	1.467	1.648	1.873	19.5	"
CdI_2	1.042	1.086	1.136	1.192	1.251	1.317	1.474	1.678	–	19.5	"
MgI_2	1.041	1.086	1.137	1.192	1.252	1.318	1.472	1.666	1.913	19.5	"
CaI_2	1.042	1.088	1.138	1.196	1.258	1.319	1.475	1.663	1.908	19.5	"
SrI_2	1.043	1.089	1.140	1.198	1.260	1.328	1.489	1.693	1.953	19.5	"
BaI_2	1.043	1.089	1.141	1.199	1.263	1.331	1.493	1.702	1.968	19.5	"
$NaClO_3$ . . .	1.035	1.068	1.106	1.145	1.188	1.233	1.329	–	–	19.5	"
$NaBrO_3$ . . .	1.039	1.081	1.127	1.176	1.229	1.287	–	–	–	19.5	"
KNO_3 . . .	1.031	1.064	1.099	1.135	–	–	–	–	–	15.	Gerlach.
$NaNO_3$ . . .	1.031	1.065	1.101	1.140	1.180	1.222	1.313	1.416	–	20.2	Schiff.
$AgNO_3$ . . .	1.044	1.090	1.140	1.195	1.255	1.322	1.479	1.675	1.918	15.	Kohlrausch.

* Compiled from two papers on the subject by Gerlach in the "Zeit. für Anal. Chim.," vols. 8 and 27.

TABLE 123 *(continued)*

DENSITY OF AQUEOUS SOLUTIONS

Substance.	Weight of the dissolved substance in 100 parts by weight of the solution.									Temp. C.	Authority.
	5	10	15	20	25	30	40	50	60		
NH_4NO_3	1.020	1.041	1.063	1.085	1.107	1.131	1.178	1.229	1.282	17.5	Gerlach.
$Zn(NO_3)_2$	1.048	1.095	1.146	1.201	1.263	1.325	1.456	1.597	–	17.5	Franz.
$Zn(NO_3)_2+6H_2O$	–	1.054	–	1.113	–	1.178	1.250	1.329	–	14.	Oudemans.
$Ca(NO_3)_2$	1.037	1.075	1.118	1.162	1.211	1.260	1.367	1.482	1.604	17.5	Gerlach.
$Cu(NO_3)_2$	1.044	1.093	1.143	1.203	1.263	1.328	1.471	–	–	17.5	Franz.
$Sr(NO_3)_2$	1.039	1.083	1.129	1.179	–	–	–	–	–	19.5	Kremers.
$Pb(NO_3)_2$	1.043	1.091	1.143	1.199	1.262	1.332	–	–	–	17.5	Gerlach.
$Cd(NO_3)_2$	1.052	1.097	1.150	1.212	1.283	1.355	1.536	1.759	–	17.5	Franz.
$Co(NO_3)_2$	1.045	1.090	1.137	1.192	1.252	1.318	1.465	–	–	17.5	"
$Ni(NO_3)_2$	1.045	1.090	1.137	1.192	1.252	1.318	1.465	–	–	17.5	"
$Fe_2(NO_3)_6$	1.039	1.076	1.117	1.160	1.210	1.261	1.373	1.496	1.657	17.5	"
$Mg(NO_3)_2+6H_2O$	1.018	1.038	1.060	1.082	1.105	1.129	1.179	1.232	–	21	Schiff.
$Mn(NO_3)_2+6H_2O$	1.025	1.052	1.079	1.108	1.138	1.169	1.235	1.307	1.386	8	Oudemans.
K_2CO_3	1.044	1.092	1.141	1.192	1.245	1.300	1.417	1.543	–	15	Gerlach.
$K_2CO_3 + 2H_2O$	1.037	1.072	1.110	1.150	1.191	1.233	1.320	1.415	1.511	15.	"
$Na_2CO_3 10H_2O$	1.019	1.038	1.057	1.077	1.098	1.118	–	–	–	15.	"
$(NH_4)_2SO_4$	1.027	1.055	1.084	1.113	1.142	1.170	1.226	1.287	–	19.	Schiff.
$Fe_2(SO_4)_3$	1.045	1.096	1.150	1.207	1.270	1.336	1.489	–	–	18.	Hager.
$FeSO_4 + 7H_2O$	1.025	1.053	1.081	1.111	1.141	1.173	1.238	–	–	17.2	Schiff.
$MgSO_4$	1.051	1.104	1.161	1.221	1.284	–	–	–	–	15	Gerlach.
$MgSO_4 + 7H_2O$	1.025	1.050	1.075	1.101	1.129	1.155	1.215	1.278	–	15.	"
$Na_2SO_4 + 10H_2O$	1.019	1.039	1.059	1.081	1.102	1.124	–	–	–	15.	"
$CuSO_4 + 5H_2O$	1.031	1.064	1.098	1.134	1.173	1.213	–	–	–	18.	Schiff.
$MnSO_4 + 4H_2O$	1.031	1.064	1.099	1.135	1.174	1.214	1.303	1.398	–	15.	Gerlach.
$ZnSO_4 + 7H_2O$	1.027	1.057	1.089	1.122	1.156	1.191	1.269	1.351	1.443	20.5	Schiff.
$Fe_2(SO_4)_3 \cdot K_2SO_4 + 24H_2O$	1.026	1.045	1.066	1.088	1.112	1.141	–	–	–	17.5	Franz.
$Cr_2(SO_4)_3 \cdot K_2SO_4 + 24H_2O$	1.016	1.033	1.051	1.073	1.099	1.126	1.188	1.287	1.454	17.5	"
$MgSO_4 + K_2SO_4 + 6H_2O$	1.032	1.066	1.101	1.138	–	–	–	–	–	15.	Schiff.
$(NH_4)_2SO_4 + FeSO_4 + 6H_2O$	1.028	1.058	1.090	1.122	1.154	1.191	–	–	–	19.	"
K_2CrO_4	1.039	1.082	1.127	1.174	1.225	1.279	1.397	–	–	19.5	"
$K_2Cr_2O_7$	1.035	1.071	1.108	–	–	–	–	–	–	19.5	Kremers.
$Fe(Cy)_6K_4$	1.028	1.059	1.092	1.126	–	–	–	–	–	15.	Schiff.
$Fe(Cy)_6K_3$	1.025	1.053	1.070	1.113	–	–	–	–	–	13	"
$Pb(C_2H_3O_2)_2 + 3H_2O$	1.031	1.064	1.100	1.137	1.177	1.220	1.315	1.426	–	15.	Gerlach.
$2NaOH + As_2O_5 + 24H_2O$	1.020	1.042	1.066	1.089	1.114	1.140	1.194	–	–	14.	Schiff.

Substance.	5	10	15	20	30	40	60	80	100	Temp. C.	Authority.
SO_3	1.040	1.084	1.132	1.179	1.277	1.389	1.564	1.840	–	15.	Brineau.
SO_2	1.013	1.028	1.045	1.063	–	–	–	–	–	4.	Schiff.
N_2O_5	1.033	1.069	1.104	1.141	1.217	1.294	1.422	1.506	–	15.	Kolb.
$C_4H_6O_6$	1.021	1.047	1.070	1.096	1.150	1.207	–	–	–	15.	Gerlach.
$C_6H_8O_7$	1.018	1.038	1.058	1.079	1.123	1.170	1.273	–	–	15.	"
Cane sugar	1.019	1.039	1.060	1.082	1.129	1.178	1.289	–	–	17.5	"
HCl	1.025	1.050	1.075	1.101	1.151	1.200	–	–	–	15.	Kolb.
HBr	1.035	1.073	1.114	1.158	1.257	1.376	–	–	–	14.	Topsöe.
HI	1.037	1.077	1.118	1.165	1.271	1.400	–	–	–	13.	"
H_2SO_4	1.032	1.069	1.106	1.145	1.223	1.307	1.501	1.732	1.838	15.	Kolb.
H_2SiF_6	1.040	1.082	1.127	1.174	1.273	–	–	–	–	17.5	Stolba.
P_2O_5	1.035	1.077	1.119	1.167	1.271	1.385	1.676	–	–	17.5	Hager.
$P_2O_5 + 3H_2O$	1.027	1.057	1.086	1.119	1.188	1.264	1.438	–	–	15.	Schiff.
HNO_3	1.028	1.056	1.088	1.119	1.184	1.250	1.373	1.459	1.528	15.	Kolb.
$C_2H_4O_2$	1.007	1.014	1.021	1.028	1.041	1.052	1.068	1.075	1.055	15.	Oudemans.

TABLE 124

DENSITY OF MIXTURES OF ETHYL ALCOHOL AND WATER IN GRAMS PER MILLILITER

The densities in this table are numerically the same as specific gravities at the various temperatures in terms of water at 4° C as unity. Based upon work done at U. S. Bureau of Standards. See Bulletin Bur. Stds. vol. 9, no. 3; contains extensive bibliography; also Circular 19, 1913.

Per cent C_2H_5OH by weight	Temperatures.						
	10° C.	15° C.	20° C.	25° C.	30° C.	35° C.	40° C.
0	0.99973	0.99913	0.99823	.99708	0.99568	0.99406	0.99225
1	785	725	636	520	379	217	034
2	602	542	453	336	194	031	.98846
3	426	365	275	157	014	.98849	663
4	258	195	103	.98984	.98839	672	485
5	098	032	.98938	817	670	501	311
6	.98946	.98877	780	656	507	335	142
7	801	729	627	500	347	172	.97975
8	660	584	478	346	189	009	808
9	524	442	331	193	031	.97846	641
10	393	304	187	043	.97875	685	475
11	267	171	047	.97897	723	527	312
12	145	041	.97910	753	573	371	150
13	026	.97914	775	611	424	216	.96989
14	.97911	790	643	472	278	063	829
15	800	669	514	334	133	.96911	670
16	692	552	387	199	.96990	760	512
17	583	433	259	062	844	607	352
18	473	313	129	.96923	697	452	189
19	363	191	.96997	782	547	294	023
20	252	068	864	639	395	134	.95856
21	139	.96944	729	495	242	.95973	687
22	024	818	592	348	087	809	516
23	.96907	689	453	199	.95929	643	343
24	787	558	312	048	769	476	168
25	665	424	168	.95895	607	306	.94991
26	539	287	020	738	442	133	810
27	406	144	.95867	576	272	.94955	625
28	268	.95996	710	410	098	774	438
29	125	844	548	241	.94922	590	248
30	.95977	686	382	067	741	403	055
31	823	524	212	.94890	557	214	.93860
32	665	357	038	709	370	021	662
33	502	186	.94860	525	180	.93825	461
34	334	011	679	337	.93986	626	257
35	162	.94832	494	146	790	425	051
36	.94986	650	306	.93952	591	221	.92843
37	805	464	114	756	390	016	634
38	620	273	.93919	556	186	.92808	422
39	431	079	720	353	.92979	597	208
40	238	.93882	518	148	770	385	.91992
41	042	682	314	.92940	558	170	774
42	.93842	478	107	729	344	.91952	554
43	639	271	.92897	516	128	733	332
44	433	062	685	301	.91910	513	108
45	226	.92852	472	085	692	291	.90884
46	017	640	257	.91868	472	069	660
47	.92806	426	041	649	250	.90845	434
48	593	211	.91823	429	028	621	207
49	379	.91995	604	208	.90805	396	.89979
50	162	776	384	.90985	580	168	750

DENSITY OF MIXTURES OF ETHYL ALCOHOL AND WATER IN GRAMS PER MILLILITER

Per cent C_2H_5OH by weight	Temperature.						
	10° C.	15° C.	20° C.	25° C.	30° C.	35° C.	40° C.
50	0.92162	0.91776	0.91384	0.90985	0.90580	0.90168	0.89750
51	.91943	555	160	760	353	.89940	519
52	723	333	.90936	534	125	710	288
53	502	110	711	307	.89896	479	056
54	279	.90885	485	079	667	248	.88823
55	055	659	258	.89850	437	016	589
56	.90831	433	031	621	206	.88784	356
57	607	207	.89803	392	.88975	552	122
58	381	.89980	574	162	744	319	.87888
59	154	752	344	.88931	512	085	653
60	.89927	523	113	699	278	.87851	417
61	698	293	.88882	466	044	615	180
62	468	062	650	233	.87809	379	.86943
63	237	.88830	417	.87998	574	142	705
64	006	597	183	763	337	.86905	466
65	.88774	364	.87948	527	100	667	227
66	541	130	713	291	.86863	429	.85987
67	308	.87895	477	054	625	190	747
68	074	660	241	.86817	387	.85950	507
69	.87839	424	004	579	148	710	266
70	602	187	.86766	340	.85908	470	025
71	365	.86949	527	100	667	228	.84783
72	127	710	287	.85859	426	.84986	540
73	.86888	470	047	618	184	743	297
74	648	229	.85806	376	.84941	500	053
75	408	.85988	564	134	698	257	.83809
76	168	747	322	.84891	455	013	564
77	.85927	505	079	647	211	.83768	319
78	685	262	.84835	403	.83966	523	074
79	442	018	590	158	720	277	.82827
80	197	.84772	344	.83911	473	029	578
81	.84950	525	096	664	224	.82780	329
82	702	277	.83848	415	.82974	530	079
83	453	028	599	164	724	279	.81828
84	203	.83777	348	.82913	473	027	576
85	.83951	525	095	660	220	.81774	322
86	697	271	.82840	405	.81965	519	067
87	441	014	583	148	708	262	.80811
88	181	.82754	323	.81888	448	003	552
89	.82919	492	062	626	186	.80742	291
90	654	227	.81797	362	.80922	478	028
91	386	.81959	529	094	655	211	.79761
92	114	688	257	.80823	384	.79941	491
93	.81839	413	.80983	549	111	669	220
94	561	134	705	272	.79835	393	.78947
95	278	.80852	424	.79991	555	114	670
96	.80991	566	138	706	271	.78831	388
97	698	274	.79846	415	.78981	542	100
98	399	.79975	547	117	684	247	.77806
99	094	670	243	.78814	382	.77946	507
100	.79784	360	.78934	506	075	641	203

Table 125

DENSITY OF AQUEOUS MIXTURES OF METHYL ALCOHOL, CANE SUGAR, OR SULFURIC ACID

Per cent by weight of substance.	Methyl Alcohol. $D\frac{15^\circ}{4^\circ}$ C.	Cane Sugar. 20° See p. 175	Sulphuric Acid. $D\frac{20^\circ}{4^\circ}$ C.	Per cent by weight of substance.	Methyl Alcohol. $D\frac{15^\circ}{4^\circ}$ C.	Cane Sugar. 20° See p. 175	Sulphuric Acid. $D\frac{20^\circ}{4^\circ}$ C.
0	0.99913	0.998234	0.99823	50	0.91852	1.229567	1.39505
1	.99727	1.002120	1.00506	51	.91653	1.235085	1.40487
2	.99543	1.006015	1.01178	52	.91451	1.240641	1.41481
3	.99370	1.009934	1.01839	53	.91248	1.246234	1.42487
4	.99198	1.013881	1.02500	54	.91044	1.251866	1.43503
5	.99029	1.017854	1.03168	55	.90839	1.257535	1.44530
6	.98864	1.021855	1.03843	56	.90631	1.263243	1.45568
7	.98701	1.025885	1.04527	57	.90421	1.268989	1.46615
8	.98547	1.029942	1.05216	58	.90210	1.274774	1.47673
9	.98394	1.034029	1.05909	59	.89996	1.280595	1.48740
10	.98241	1.038143	1.06609	60	.89781	1.286456	1.49818
11	.98093	1.042288	1.07314	61	.89563	1.292354	1.50904
12	.97945	1.046462	1.08026	62	.89341	1.298291	1.51999
13	.97802	1.050665	1.08744	63	.89117	1.304267	1.53102
14	.97660	1.054900	1.09468	64	.88890	1.310282	1.54213
15	.97518	1.059165	1.10199	65	.88662	1.316334	1.55333
16	.97377	1.063460	1.10936	66	.88433	1.322425	1.56460
17	.97237	1.067789	1.11679	67	.88203	1.328554	1.57595
18	.97096	1.072147	1.12428	68	.87971	1.334722	1.58739
19	.96955	1.076537	1.13183	69	.87739	1.340928	1.59890
20	.96814	1.080959	1.13943	70	.87507	1.347174	1.61048
21	.96673	1.085414	1.14709	71	.87271	1.353456	1.62213
22	.96533	1.089900	1.15480	72	.87033	1.359778	1.63384
23	.96392	1.094420	1.16258	73	.86792	1.366139	1.64560
24	.96251	1.098971	1.17041	74	.86546	1.372536	1.65738
25	.96108	1.103557	1.17830	75	.86300	1.378971	1.66917
26	.95963	1.108175	1.18624	76	.86051	1.385446	1.68095
27	.95817	1.112828	1.19423	77	.85801	1.391956	1.69268
28	.95668	1.117512	1.20227	78	.85551	1.398505	1.70433
29	.95518	1.122231	1.21036	79	.85300	1.405091	1.71585
30	.95366	1.126984	1.21850	80	.85048	1.411715	1.72717
31	.95213	1.131773	1.22669	81	.84794	1.418374	1.73827
32	.95056	1.136596	1.23492	82	.84536	1.425072	1.74904
33	.94896	1.141453	1.24320	83	.84274	1.431807	1.75943
34	.94734	1.146345	1.25154	84	.84009	1.438579	1.76932
35	.94570	1.151275	1.25992	85	.83742	1.445388	1.77860
36	.94404	1.156238	1.26836	86	.83475	1.452232	1.78721
37	.94237	1.161236	1.27685	87	.83207	1.459114	1.79509
38	.94067	1.166269	1.28543	88	.82937	1.466032	1.80223
39	.93894	1.171340	1.29407	89	.82667	1.472986	1.80864
40	.93720	1.176447	1.30278	90	.82396	1.479976	1.81438
41	.93543	1.181592	1.31157	91	.82124	1.487002	1.81950
42	.93365	1.186773	1.32043	92	.81849	1.494063	1.82401
43	.93185	1.191993	1.32938	93	.81568	1.501158	1.82790
44	.93001	1.197247	1.33843	94	.81285	1.508289	1.83115
45	.92815	1.202540	1.34759	95	.80999	1.515455	1.83368
46	.92627	1.207870	1.35686	96	.80713	1.522656	1.83548
47	.92436	1.213238	1.36625	97	.80428	1.529891	1.83637
48	.92242	1.218643	1.37574	98	.80143	1.537161	1.83605
49	.92048	1.224086	1.38533	99	.79859	1.544462	
50	.91852	1.229567	1.39505	100	.79577	1.551800	

(1) Calculated from the specific gravity determinations of Doroschevski and Rozhdestvenski at 15°/15°C; J. Russ., Phys. Chem. Soc., 41, p. 977, 1909.
(2) According to Dr. F. Plato; Wiss. Abh. der K. Normal-Eichungs-Kommission, 2, p. 153, 1900.
(3) Calculated from Dr. Domke's table; Wiss. Abh. der K. Normal-Eichungs-Kommission, 5, p. 131, 1900.

All reprinted from Circular 19, U.S. Bureau of Standards, 1913.

DENSITY, BRIX, AND BAUMÉ DEGREES, OF CANE SUGAR SOLUTIONS

Degrees Brix, Specific Gravity, and Degrees Baumé of Sugar Solutions.
Degrees Brix = Per cent Sucrose by Weight.

Specific Gravities and Degrees Baumé corresponding to the Degrees Brix are for $\frac{20^{\circ}}{20^{\circ}}$ C.

The relation between the specific gravity and Degrees Baumé is given by Degrees Baumé $= 145 - \frac{145}{\text{specific gravity}}$.

Degrees Brix or per cent sucrose by weight	Specific gravity at 20°/20°C	Degrees Baumé (modulus 145)	Degrees Brix or per cent sucrose by weight	Specific gravity at 20°/20°C	Degrees Baumé (modulus 145)	Degrees Brix or per cent sucrose by weight	Specific gravity at 20°/20°C	Degrees Baumé (modulus 145)
0.0	1.00000	0.00	40.0	1.17853	21.97	80.0	1.41421	42.47
1.0	1.00389	0.56	41.0	1.18368	22.50	81.0	1.42088	42.95
2.0	1.00779	1.12	42.0	1.18887	23.04	82.0	1.42759	43.43
3.0	1.01172	1.68	43.0	1.19410	23.57	83.0	1.43434	43.91
4.0	1.01567	2.24	44.0	1.19936	24.10	84.0	1.44112	44.38
5.0	1.01965	2.79	45.0	1.20467	24.63	85.0	1.44794	44.86
6.0	1.02366	3.35	46.0	1.21001	25.17	86.0	1.45480	45.33
7.0	1.02770	3.91	47.0	1.21538	25.70	87.0	1.46170	45.80
8.0	1.03176	4.46	48.0	1.22080	26.23	88.0	1.46862	46.27
9.0	1.03586	5.02	49.0	1.22625	26.75	89.0	1.47559	46.73
10.0	1.03998	5.57	50.0	1.23174	27.28	90.0	1.48259	47.20
11.0	1.04413	6.13	51.0	1.23727	27.81	91.0	1.48963	47.66
12.0	1.04831	6.68	52.0	1.24284	28.33	92.0	1.49671	48.12
13.0	1.05252	7.24	53.0	1.24844	28.86	93.0	1.50381	48.58
14.0	1.05677	7.79	54.0	1.25408	29.38	94.0	1.51096	49.03
15.0	1.06104	8.34	55.0	1.25976	29.90	95.0	1.51814	49.49
16.0	1.06534	8.89	56.0	1.26548	30.42	96.0	1.52535	49.94
17.0	1.06968	9.45	57.0	1.27123	30.94	97.0	1.53260	50.39
18.0	1.07404	10.00	58.0	1.27703	31.46	98.0	1.53988	50.84
19.0	1.07844	10.55	59.0	1.28286	31.97	99.0	1.54719	51.28
20.0	1.08287	11.10	60.0	1.28873	32.49	100.0	1.55454	51.73
21.0	1.08733	11.65	61.0	1.29464	33.00			
22.0	1.09183	12.20	62.0	1.30059	33.51			
23.0	1.09636	12.74	63.0	1.30657	34.02			
24.0	1.10092	13.29	64.0	1.31260	34.53			
25.0	1.10551	13.84	65.0	1.31866	35.04			
26.0	1.11014	14.39	66.0	1.32476	35.55			
27.0	1.11480	14.93	67.0	1.33090	36.05			
28.0	1.11949	15.48	68.0	1.33708	36.55			
29.0	1.12422	16.02	69.0	1.34330	37.06			
30.0	1.12898	16.57	70.0	1.34956	37.56			
31.0	1.13378	17.11	71.0	1.35585	38.06			
32.0	1.13861	17.65	72.0	1.36218	38.55			
33.0	1.14347	18.19	73.0	1.36856	39.05			
34.0	1.14837	18.73	74.0	1.37496	39.54			
35.0	1.15331	19.28	75.0	1.38141	40.03			
36.0	1.15828	19.81	76.0	1.38790	40.53			
37.0	1.16329	20.35	77.0	1.39442	41.01			
38.0	1.16833	20.89	78.0	1.40098	41.50			
39.0	1.17341	21.43	79.0	1.40758	41.99			

The above table is abridged from Bureau of Standards Technologic Paper No. 115. The original table is given in steps of 0.1 Degrees Brix.

Table 127

DENSITY OF GASES

The following table gives the density as the weight in grams of a liter (normal liter) of the gas at 0°C, 76 cm pressure, and standard gravity, 980.665 cm/sec.^{2}, (sea-level, 45° latitude), the specific gravity referred to dry, carbon-dioxide-free air, and to pure oxygen, and the weight in pounds per cubic foot. Dry, carbon-dioxide-free air is of remarkably uniform density; Guye, Kovacs and Wourtzel found maximum variations in the density of only 7 to 8 parts in 10,000. For highest accuracy pure oxygen should be used as the standard gas for specific gravities. Observed densities are closely proportional to the molecular weights. The following table was prepared by the Gas Chemistry Section, Bur. Standards, 1929.

Gas	Formula	Weight of normal liter in grams	Air = 1	O_2 = 1	Pounds per cubic foot	Reference
Air	....	1.2929	1.0000	.9047	.08071	1
Acetylene	C_2H_2	1.173	.907	.8208	.07323	1
Ammonia	NH_3	.7710	.5963	.5395	.04813	1
Argon	A	1.7837	1.3796	1.2482	.11135	2
Arsine	AsH_3	3.48	2.69	2.44	.217	1
Butane-iso	C_4H_{10}	2.673	2.067	1.870	.1669	1
Butane-n	C_4H_{10}	2.519_0 at 710 mm	2.085_4*	1.886_8*	$.1572_5$*	5, 6
Carbon dioxide	CO_2	1.9769	1.5290	1.3834	.12341	1
Carbon monoxide	CO	1.2504	.9671	.8750	.07806	1
Carbon oxysulphide	COS	2.72	2.10	1.90	.170	1
Chlorine	Cl_2	3.214	2.486	2.249	.2006	1
Chlorine monoxide	Cl_2O	3.89	3.01	2.72	.243	1
Ethane	C_2H_6	1.3566	1.0493	.9493	.08469	1
Ethylene	C_2H_4	1.2604	.9749	.8820	.07868	1
Fluorine	F_2	1.696	1.312	1.187	.1059	1
Helium	He	$.1784_7$	$.1380_4$	$.1248_9$	$.01114_2$	1
Hydrogen	H_2	.08988	.06952	.06290	.005611	1
Hydrogen bromide	HBr	3.6445	2.8189	2.5503	.22752	1
Hydrogen chloride	HCl	1.6392	1.2678	1.1471	.10233	1
Hydrogen iodide	HI	5.789_1	4.477_6	4.051_0	$.3614_0$	1
Hydrogen selenide	H_2Se	3.670	2.839	2.568	.229	1
Hydrogen sulphide	H_2S	1.539	1.190	1.077	.09608	1
Krypton	Kr	3.70_8	2.86_8	2.59_5	$.231_5$	1
Methane	CH_4	$.716_8$	$.554_4$	$.501_6$	$.0447_5$	1
Monomethylamine	CH_3NH_2	1.396	1.080	.9769	.08715	1
Methyl chloride	CH_3Cl	2.3076	1.7848	1.6148	.14406	1
Methyl ether	$(CH_3)_2O$	2.1098	1.6318	1.4764	.13171	1
Methyl fluoride	CH_3F	1.5452	1.1951	1.0813	.09646	1
Neon	Ne	$.9003_5$	$.6963_8$	$.6300_4$	$.05620_7$	3
Nitric oxide	NO	1.3402	1.0366	.9378	.08367	1
Nitrogen (chem)	N_2	1.2505_5	$.9672_4$	$.8751_0$	$.07806_9$	1, 4
Nitrogen (atm)	....	1.2568	.9721	.8795	.07846	1
Nitrosyl chloride	$NOCl$	2.992	2.314	2.094	.1868	1
Nitrous oxide	N_2O	1.977_8	1.529_7	1.384_0	$.1234_7$	1
Oxygen	O_2	1.42904	1.10527	1.0000	.089212	1
Phosphine	PH_3	1.529_4	1.182_9	1.070_2	$.0954_8$	1
Propane	C_3H_8	2.020	1.562	1.414	.1261	1
Silicon tetrafluoride	SiF_4	4.68_4	3.62_3	3.27_8	$.292_4$	1
Sulphur dioxide	SO_2	2.9269	2.2638	2.0482	.18272	1
Xenon	X	5.85_1	4.52_6	4.09_4	$.365_3$	1

* Both butane and air at 710 mm.
1. Based on densities in I. C. T., 3, 3, 1928.
2. Baxter and Starkweather, Proc. Nat. Acad. Sci., 14, 57, 1928.
3. Baxter and Starkweather, Proc. Nat. Acad. Sci., 14, 50, 1928.
4. Moles and Clavera, Z. Anorg. Allgem. Chem., 167, 49, 1927.
5. Bogaert, Bull. Soc. Chim. Belg., 36, 384, 1927.
6. Beckers, Bull. Soc. Chim. Belg., 36, 559, 1927.

RELATIVE DENSITY OF MOIST AIR FOR DIFFERENT PRESSURES AND HUMIDITIES

TABLE 128.—Values of $\frac{h}{760}$, from $h=1$ to $h=9$, for the Computation of Different Values of the Ratio of Actual to Normal Barometric Pressure

This gives the density of moist air at pressure h in terms of the same air at normal atmosphere pressure. When air contains moisture, as is usually the case with the atmosphere, we have the following equation for pressure term: $h=B-0.378e$, where e is the vapor pressure, and B the corrected barometric pressure. When the necessary psychrometric observations are made the value of e may be taken from Table 212 and then $0.378e$ from Table 130, or the dew point may be found and the value of $0.378e$ taken from Table 130.

h	$\frac{h}{760}$
1	0.0013158
2	.0026316
3	.0039474
4	0.0052632
5	.0065789
6	.0078947
7	0.0092105
8	.0105263
9	.0118421

EXAMPLES OF USE OF THE TABLE.

To find the value of $\frac{h}{760}$ when $h = 754.3$

$h =$ 700	gives	.92105
50	"	.065789
4	"	.005263
.3	"	.000395
754.3		.992497

To find the value of $\frac{h}{760}$ when $h = 5.73$

$h =$ 5	gives	.0065789
.7	"	.0009210
.03	"	.0000395
5.73		.0075394

TABLE 129.—Values of the logarithms of $\frac{h}{760}$ for values of h between 80 and 800

Values from 8 to 80 may be got by subtracting 1 f om the characteristic, and from 0.8 to 8 by subtracting 2 from the characteristic, and so on.

h	Values of $\log \frac{h}{760}$									
	0	1	2	3	4	5	6	7	8	9
80	$\bar{1}.02228$	$\bar{1}.02767$	$\bar{1}.03300$	$\bar{1}.03826$	$\bar{1}.04347$	$\bar{1}.04861$	$\bar{1}.05368$	$\bar{1}.05871$	$\bar{1}.06367$	$\bar{1}.06858$
90	.07343	.07823	.08297	.08767	.09231	.09691	.10146	.10596	.11041	.11482
100	$\bar{1}.11919$	$\bar{1}.12351$	$\bar{1}.12779$	$\bar{1}.13202$	$\bar{1}.13622$	$\bar{1}.14038$	$\bar{1}.14449$	$\bar{1}.14857$	$\bar{1}.15261$	$\bar{1}.15661$
110	.16058	.16451	.16840	.17226	.17609	.17988	.18364	.18737	.19107	.19473
120	.19837	.20197	.20555	.20909	.21261	.21611	.21956	.22299	.22640	.22978
130	.23313	.23646	.23976	.24304	.24629	.24952	.25273	.25591	.25907	.26220
140	.26531	.26841	.27147	.27452	.27755	.28055	.28354	.28650	.28945	.29237
150	$\bar{1}.29528$	$\bar{1}.29816$	$\bar{1}.30103$	$\bar{1}.30388$	$\bar{1}.30671$	$\bar{1}.30952$	$\bar{1}.31231$	$\bar{1}.31509$	$\bar{1}.31784$	$\bar{1}.32058$
160	.32331	.32601	.32870	.33137	.33403	.33667	.33929	.34190	.34450	.34707
170	.34964	.35218	.35471	.35723	.35974	.36222	.36470	.36716	.36961	.37204
180	.37446	.37686	.37926	.38164	.38400	.38636	.38870	.39128	.39334	.39565
190	.39794	.40022	.40249	.40474	.40699	.40922	.41144	.41365	.41585	.41804
200	$\bar{1}.42022$	$\bar{1}.42238$	$\bar{1}.42454$	$\bar{1}.42668$	$\bar{1}.42882$	$\bar{1}.43094$	$\bar{1}.43305$	$\bar{1}.43516$	$\bar{1}.43725$	$\bar{1}.43933$
210	.44141	.44347	.44552	.44757	.44960	.45162	.45364	.45565	.45764	.45963
220	.46161	.46358	.46554	.46749	.46943	.47137	.47329	.47521	.47712	.47902
230	.48091	.48280	.48467	.48654	.48840	.49025	.49210	.49393	.49576	.49758
240	.49940	.50120	.50300	.50479	.50658	.50835	.51012	.51188	.51364	.51539
250	$\bar{1}.51713$	$\bar{1}.51886$	$\bar{1}.52059$	$\bar{1}.52231$	$\bar{1}.52402$	$\bar{1}.52573$	$\bar{1}.52743$	$\bar{1}.52912$	$\bar{1}.53081$	$\bar{1}.53249$
260	.53416	.53583	.53749	.53914	.54079	.54243	.54407	.54570	.54732	.54894
270	.55055	.55216	.55376	.55535	.55694	.55852	.56010	.56167	.56323	.56479
280	.56634	.56789	.56944	.57097	.57250	.57403	.57555	.57707	.57858	.58008
290	.58158	.58308	.58457	.58605	.58753	.58901	.59048	.59194	.59340	.59486
300	$\bar{1}.59631$	$\bar{1}.59775$	$\bar{1}.59919$	$\bar{1}.60063$	$\bar{1}.60206$	$\bar{1}.60349$	$\bar{1}.60491$	$\bar{1}.60632$	$\bar{1}.60774$	$\bar{1}.60914$
310	.61055	.61195	.61334	.61473	.61611	.61750	.61887	.62025	.62161	.62298
320	.62434	.62569	.62704	.62839	.62973	.63107	.63240	.63373	.63506	.63638
330	.63770	.63901	.64032	.64163	.64293	.64423	.64553	.64682	.64810	.64939
340	.65067	.65194	.65321	.65448	.65574	.65701	.65826	.65952	.66077	.66201

TABLE 129 (*continued*)

DENSITY OF MOIST AIR

Values of logarithms of $\frac{h}{760}$ for values of h between 80 and 800

h	Values of log $\frac{h}{760}$									
	0	1	2	3	4	5	6	7	8	9
350	$\bar{1}$.66325	$\bar{1}$.66449	$\bar{1}$.66573	$\bar{1}$.66696	$\bar{1}$.66819	$\bar{1}$.66941	$\bar{1}$.67064	$\bar{1}$.67185	$\bar{1}$.67307	$\bar{1}$.67428
360	.67549	.67669	.67790	.67909	.68029	.68148	.68267	.68385	.68503	.68621
370	.68739	.68856	.68973	.69090	.69206	.69322	.69437	.69553	.69668	.69783
380	.69897	.70011	.70125	.70239	.70352	.70465	.70577	.70690	.70802	.70914
390	.71025	.71136	.71247	.71358	.71468	.71578	.71688	.71798	.71907	.72016
400	$\bar{1}$.72125	$\bar{1}$.72233	$\bar{1}$.72341	$\bar{1}$.72449	$\bar{1}$.72557	$\bar{1}$.72664	$\bar{1}$.72771	$\bar{1}$.72878	$\bar{1}$.72985	$\bar{1}$.73091
410	.73197	.73303	.73408	.73514	.73619	.73723	.73828	.73932	.74036	.74140
420	.74244	.74347	.74450	.74553	.74655	.74758	.74860	.74961	.75063	.75164
430	.75265	.75366	.75467	.75567	.75668	.75768	.75867	.75967	.76066	.76165
440	.76264	.76362	.76461	.76559	.76657	.76755	.76852	.76949	.77046	.77143
450	$\bar{1}$.77240	$\bar{1}$.77336	$\bar{1}$.77432	$\bar{1}$.77528	$\bar{1}$.77624	$\bar{1}$.77720	$\bar{1}$.77815	$\bar{1}$.77910	$\bar{1}$.78005	$\bar{1}$.78100
460	.78194	.78289	.78383	.78477	.78570	.78664	.78757	.78850	.78943	.79036
470	.79128	.79221	.79313	.79405	.79496	.79588	.79679	.79770	.79861	.79952
480	.80043	.80133	.80223	.80313	.80403	.80493	.80582	.80672	.80761	.80850
490	.80938	.81027	.81115	.81203	.81291	.81379	.81467	.81554	.81642	.81729
500	$\bar{1}$.81816	$\bar{1}$.81902	$\bar{1}$.81989	$\bar{1}$.82075	$\bar{1}$.82162	$\bar{1}$.82248	$\bar{1}$.82334	$\bar{1}$.82419	$\bar{1}$.82505	$\bar{1}$.82590
510	.82676	.82761	.82846	.82930	.83015	.83099	.83184	.83268	.83352	.83435
520	.83519	.83602	.83686	.83769	.83852	.83935	.84017	.84100	.84182	.84264
530	.84346	.84428	.84510	.84591	.84673	.84754	.84835	.84916	.84997	.85076
540	.85158	.85238	.85319	.85399	.85479	.85558	.85638	.85717	.85797	.85876
550	$\bar{1}$.85955	$\bar{1}$.86034	$\bar{1}$.86113	$\bar{1}$.86191	$\bar{1}$.86270	$\bar{1}$.86348	$\bar{1}$.86426	$\bar{1}$.86504	$\bar{1}$.86582	$\bar{1}$.86660
560	.86737	.86815	.86892	.86969	.87047	.87123	.87200	.87277	.87353	.87430
570	.87506	.87582	.87658	.87734	.87810	.87885	.87961	.88036	.88111	.88186
580	.88261	.88336	.88411	.88486	.88560	.88634	.88708	.88782	.88856	.88930
590	.89004	.89077	.89151	.89224	.89297	.89370	.89443	.89516	.89589	.89661
600	$\bar{1}$.89734	$\bar{1}$.89806	$\bar{1}$.89878	$\bar{1}$.89950	$\bar{1}$.90022	$\bar{1}$.90094	$\bar{1}$.90166	$\bar{1}$.90238	$\bar{1}$.90309	$\bar{1}$.90380
610	.90452	.90523	.90594	.90665	.90735	.90806	.90877	.90947	.91017	.91088
620	.91158	.91228	.91298	.91367	.91437	.91507	.91576	.91645	.91715	.91784
630	.91853	.91922	.91990	.92059	.92128	.92196	.92264	.92333	.92401	.92469
640	.92537	.92604	.92672	.92740	.92807	.92875	.92942	.93009	.93076	.93143
650	$\bar{1}$.93210	$\bar{1}$.93277	$\bar{1}$.93343	$\bar{1}$.93410	$\bar{1}$.93476	$\bar{1}$.93543	$\bar{1}$.93609	$\bar{1}$.93675	$\bar{1}$.93741	$\bar{1}$.93807
660	.93873	.93939	.94004	.94070	.94135	.94201	.94266	.94331	.94396	.94461
670	.94526	.94591	.94656	.94720	.94785	.94849	.94913	.94978	.95042	.95106
680	.95170	.95233	.95297	.95361	.95424	.95488	.95551	.95614	.95677	.95741
690	.95804	.95866	.95929	.95992	.96055	.96117	.96180	.96242	.96304	.96366
700	$\bar{1}$.96428	$\bar{1}$.96490	$\bar{1}$.96552	$\bar{1}$.96614	$\bar{1}$.96676	$\bar{1}$.96738	$\bar{1}$.96799	$\bar{1}$.96861	$\bar{1}$.96922	$\bar{1}$.96983
710	.97044	.97106	.97167	.97228	.97288	.97349	.97410	.97471	.97531	.97592
720	.97652	.97712	.97772	.97832	.97892	.97951	.98012	.98072	.98132	.98191
730	.98251	.98310	.98370	.98429	.98488	.98547	.98606	.98665	.98724	.98783
740	.98842	.98900	.98959	.99018	.99076	.99134	.99193	.99251	.99309	.99367
750	$\bar{1}$.99425	$\bar{1}$.99483	$\bar{1}$.99540	$\bar{1}$.99598	$\bar{1}$.99656	$\bar{1}$.99713	$\bar{1}$.99771	$\bar{1}$.99828	$\bar{1}$.99886	$\bar{1}$.99942
760	0.00000	0 00057	0.00114	0.00171	0.00228	0.00285	0.00342	0.00398	0.00455	0.00511
770	.00568	.00624	.00680	.00737	.00793	.00849	.00905	.00961	.01017	.01072
780	.01128	.01184	.01239	.01295	.01350	.01406	.01461	.01516	.01571	.01626
790	.01681	.01736	.01791	.01846	.01901	.01955	.02010	.02064	.02119	.02173

DENSITY OF MOIST AIR

TABLE 130. — Values of 0.378e *

This table gives the humidity term $0.378e$, which occurs in the equation $\delta = \delta_0 \frac{h}{760} = \delta_0 \frac{B - 0.378e}{760}$ for the calculation of the density of air containing aqueous vapor at pressure e; δ_0 is the density of dry air at normal temperature and barometric pressure, B the observed barometric pressure, and $h = B - 0.378e$, the pressure corrected for humidity. For values of $\frac{h}{760}$, see Table 128. Temperatures are in degrees Centigrade, and pressures in millimeters of mercury.

Dew point.	e Vapor pressure (ice).	0.378e	Dew point.	e Vapor pressure (water).	0.378e	Dew point.	e Vapor pressure (water).	0.378e
C	mm	mm	C	mm	mm	C	mm	mm
−50°	0.029	0.01	**0°**	4.58	1.73	**30°**	31.86	12.0
−45	0.054	0.02	1	4.92	1.86	31	33.74	12.8
−40	0.096	0.04	2	5.29	2.00	32	35.70	13.5
−35	0.169	0.06	3	5.68	2.15	33	37.78	14.3
−30	0.288	0.11	4	6.10	2.31	34	39.95	15.1
−25	0.480	0.18	**5**	6.54	2.47	**35**	42.23	16.0
24	0.530	0.20	6	7.01	2.66	36	44.62	16.9
23	0.585	0.22	7	7.51	2.84	37	47.13	17.8
22	0.646	0.24	8	8.04	3.04	38	49.76	18.8
21	0.712	0.27	9	8.61	3.25	39	52.51	19.8
−20	0.783	0.30	**10**	9.21	3.48	**40**	55.40	20.9
19	0.862	0.33	11	9.85	3.72	41	58.42	22.1
18	0.947	0.36	12	10.52	3.98	42	61.58	23.3
17	1.041	0.39	13	11.24	4.25	43	64.89	24.5
16	1.142	0.43	14	11.99	4.53	44	68.35	25.8
−15	1.252	0.47	**15**	12.79	4.84	**45**	71.97	27.2
14	1.373	0.52	16	13.64	5.16	46	75.75	28.6
13	1.503	0.57	17	14.54	5.50	47	79.70	30.1
12	1.644	0.62	18	15.49	5.85	48	83.83	31.7
11	1.798	0.68	19	16.49	6.23	49	88.14	33.3
−10	1.964	0.74	**20**	17.55	6.63	**50**	92.6	35.0
9	2.144	0.81	21	18.66	7.06	51	97.3	36.8
8	2.340	0.88	22	19.84	7.50	52	102.2	38.6
7	2.550	0.96	23	21.09	7.97	53	107.3	40.6
6	2.778	1.05	24	22.40	8.47	54	112.7	42.6
−5	3.025	1.14	**25**	23.78	8.99	**55**	118.2	44.7
4	3.291	1.24	26	25.24	9.54	56	124.0	46.9
3	3.578	1.35	27	26.77	10.12	57	130.0	49.1
2	3.887	1.47	28	28.38	10.73	58	136.3	51.5
1	4.220	1.60	29	30.08	11.37	59	142.8	54.0
0	4.580	1.73	**30**	31.86	12.04	**60**	149.6	56.5

* Table quoted from Smithsonian Meteorological Tables.

TABLE 131. — Maintenance of Air at Definite Humidities

Taken from Stevens, Phytopathology, 6, 428, 1916; see also Curtis, Bul. Bur. Standards, 11, 359, 1914; Dieterici, Ann. d. Phys. u. Chem., 50, 47, 1893. The relative humidity and vapor pressure of aqueous vapor of moist air in equilibrium conditions above aqueous solutions of sulphuric acid are given below.

Density of acid sol.	Relative humidity.	Vapor pressure.		Density of acid sol.	Relative humidity.	Vapor pressure.	
		20° C	30° C			20° C	30° C
		mm	mm			mm	mm
1.00	100.0	17.4	31.6	1.30	58.3	10.1	18.4
1.05	97.5	17.0	30.7	1.35	47.2	8.3	15.0
1.10	93.9	16.3	29.6	1.40	37.1	6.5	11.9
1.15	88.8	15.4	28.0	1.50	18.8	3.3	6.0
1.20	80.5	14.0	25.4	1.60	8.5	1.5	2.7
1.25	70.4	12.2	22.2	1.70	3.2	0.6	1.0

PRESSURE OF COLUMNS OF MERCURY AND WATER

British and metric measures. Correct at 0° C for mercury and at 4° C for water.

Metric Measure.			British Measure.		
Cms. of Hg.	Pressure in grams per sq. cm.	Pressure in pounds per sq. inch.	Inches of Hg.	Pressure in grams per sq. cm.	Pressure in pounds per sq. inch.
1	13.5956	0.193376	1	34.533	0.491174
2	27.1912	0.386752	2	69.066	0.982348
3	40.7868	0.580128	3	103.598	1.473522
4	54.3824	0.773504	4	138.131	1.964696
5	67.9780	0.966880	5	172.664	2.455870
6	81.5736	1.160256	6	207.197	2.947044
7	95.1692	1.353632	7	241.730	3.438218
8	108.7648	1.547008	8	276.262	3.929392
9	122.3604	1.740384	9	310.795	4.420566
10	135.9560	1.933760	10	345.328	4.911740
Cms. of H_2O.	Pressure in grams per sq. cm.	Pressure in pounds per sq. inch.	Inches of H_2O.	Pressure in grams per sq. cm.	Pressure in pounds per sq. inch.
1	1	0.0142234	1	2.54	0.036127
2	2	0.0284468	2	5.08	0.072255
3	3	0.0426702	3	7.62	0.108382
4	4	0.0568936	4	10.16	0.144510
5	5	0.0711170	5	12.70	0.180637
6	6	0.0853404	6	15.24	0.216764
7	7	0.0995638	7	17.78	0.252892
8	8	0.1137872	8	20.32	0.289019
9	9	0.1280106	9	22.86	0.325147
10	10	0.1422340	10	25.40	0.361274

REDUCTION OF BAROMETRIC HEIGHT TO STANDARD TEMPERATURE *

Corrections for brass scale and English measure.		Corrections for brass scale and metric measure.		Corrections for glass scale and metric measure.	
Height of barometer in inches.	α in inches for temp. F.	Height of barometer in mm.	α in mm for temp. C.	Height of barometer in mm.	α in mm for temp. C.
15.0	0.00135	400	0.0651	50	0.0086
16.0	.00145	410	.0668	100	.0172
17.0	.00154	420	.0684	150	.0258
17.5	.00158	430	.0700	200	.0345
18.0	.00163	440	.0716	250	.0431
18.5	.00167	450	.0732	300	.0517
19.0	.00172	460	.0749	350	.0603
19.5	.00176	470	.0765		
		480	.0781	400	0.0689
20.0	0.00181	490	.0797	450	.0775
20.5	.00185			500	.0861
21.0	.00190	500	0.0813	520	.0895
21.5	.00194	510	.0830	540	.0930
22.0	.00199	520	.0846	560	.0965
22.5	.00203	530	.0862	580	.0999
23.0	.00208	540	.0878		
23.5	.00212	550	.0894	600	0.1034
		560	.0911	610	.1051
24.0	0.00217	570	.0927	620	.1068
24.5	.00221	580	.0943	630	.1085
25.0	.00226	590	.0959	640	.1103
25.5	.00231			650	.1120
26.0	.00236	600	0.0975	660	.1137
26.5	.00240	610	.0992		
27.0	.00245	620	.1008	670	0.1154
27.5	.00249	630	.1024	680	.1172
		640	.1040	690	.1189
28.0	0.00254	650	.1056	700	.1206
28.5	.00258	660	.1073	710	.1223
29.0	.00263	670	.1089	720	.1240
29.2	.00265	680	.1105	730	.1258
29.4	.00267	690	.1121		
29.6	.00268			740	0.1275
29.8	.00270	700	0.1137	750	.1292
30.0	.00272	710	.1154	760	.1309
		720	.1170	770	.1327
30.2	0.00274	730	.1186	780	.1344
30.4	.00276	740	.1202	790	.1361
30.6	.00277	750	.1218	800	.1378
30.8	.00279	760	.1235		
31.0	.00281	770	.1251	850	0.1464
31.2	.00283	780	.1267	900	.1551
31.4	.00285	790	.1283	950	.1639
31.6	.00287	800	.1299	1000	.1723

* The height of the barometer is affected by the relative thermal expansion of the mercury and the glass, in the case of instruments graduated on the glass tube, and by the relative expansion of the mercury and the metallic inclosing case, usually of brass, in the case of instruments graduated on the brass case. This relative expansion is practically proportional to the first power of the temperature. The above tables of values of the coefficient of relative expansion will be found to give corrections almost identical with those given in the International Meteorological Tables. The numbers tabulated under α are the values of α in the equation $H_t = H_t' - \alpha(t' - t)$ where H_t is the height at the standard temperature, H_t' the observed height at the temperature t', and $\alpha(t' - t)$ the correction for temperature. The standard temperature is 0° C for the metric system and 28°.5 F. for the English system. The English barometer is correct for the temperature of melting ice at a temperature of approximately 28°.5 F., because of the fact that the brass scale is graduated so as to be standard at 62° F., while mercury has the standard density at 32° F.

EXAMPLE.—A barometer having a brass scale gave $H = 765$ mm at 25° C; required, the corresponding reading at 0° C. Here the value of α is the mean of .1235 and .1251, or .1243; $\therefore \alpha(t' - t) = .1243 \times 25 = 3.11$. Hence $H_0 = 765 - 3.11 = 761.89$

N. B.—Although α is here given to three and sometimes to four significant figures, it is seldom worth while to use more than the nearest two-figure number. In fact, all barometers have not the same values for α, and when great accuracy is wanted the proper coefficients have to be determined by experiment.

Table 134

REDUCTION OF BAROMETER TO STANDARD GRAVITY

Free-air Altitude Term. Correction to be subtracted.

The correction to reduce the barometer to sea-level is $(g_1 - g)/g \times B$ where B is the barometer reading and g and g_1 the value of gravity at sea-level and the place of observation respectively. The following values were computed for free-air values of gravity g_1 (Table 706). It has been customary to assume for mountain stations that the value of g_1 = say about $\frac{2}{3}$ the free-air value, but a comparison of modern determinations of g_1 in this country shows that little reliance can be placed on such an assumption. Where g_1 is known its value should be used in the above correction term. (See Tables 707 to 709. Similarly for the latitude term, see succeeding tables, the true value of g should be used if known; the succeeding tables are based on the theoretical values, Table 706.)

Height above sea-level.	$g_1 - g$	Observed height of barometer in millimeters. 400	450	500	550	600	650	700	750	800		
meters.												
100	0.031	Correction in mm to be subtracted for height above sea-level in first column and barometer reading in the top line.						.02	.02	.02	—	—
200	0.062							.04	.05	.05	—	—
300	0.093							.07	.07	.07	—	—
400	0.123							.09	.10	.10	—	—
500	0.154	—	—	—	—	—	—	.11	.12	.13	—	—
600	0.185	—	—	—	—	—	.12	.13	.14	—	—	—
700	0.216	—	—	—	—	—	.14	.15	.16	—	—	—
800	0.247	—	—	—	—	—	.16	.18	.19	—	—	—
900	0.278	—	—	—	—	—	.18	.20	.22	—	—	—
1000	0.309	—	—	—	.18	.19	.20	.22	.24	—	—	—
1100	0.339	—	—	—	.19	.21	.22	.24	—	—	—	—
1200	0.370	—	—	—	.21	.23	.24	.26	—	—	—	—
1300	0.401	—	—	—	.22	.24	.26	.29	—	—	—	—
1400	0.432	—	—	—	.24	.26	.28	.31	—	—	—	—
1500	0.463	—	—	.24	.26	.28	.30	.33	—	—	—	—
1600	0.494	—	—	.25	.28	.30	.32	—	—	—	—	—
1700	0.525	—	—	.27	.30	.32	.34	—	—	—	—	—
1800	0.555	—	—	.28	.31	.34	.36	—	—	.020	.0463	15000
1900	0.586	—	—	.30	.33	.36	.39	—	—	.019	.0447	14500
2000	0.617	—	.28	.31	.34	.38	.41	—	.021	.019	.0432	14000
2100	0.648	—	.30	.33	.36	.40	—	—	.021	.018	.0416	13500
2200	0.679	—	.31	.35	.38	.41	—	—	.020	.017	.0401	13000
2300	0.710	—	.32	.36	.40	.43	—	.021	.019	.017	.0386	12500
2400	0.740	—	.34	.38	.42	.45	—	.021	.018	.016	.0370	12000
2500	0.771	.31	.35	.39	.43	.47	—	.020	.018	.015	.0355	11500
2600	0.802	.33	.37	.41	—	—	.021	.019	.017	.015	.0339	11000
2700	0.833	.34	.38	.42	—	—	.020	.018	.016	.014	.0324	10500
2800	0.864	.35	.40	.44	—	—	.019	.017	.015	.013	.0308	10000
2900	0.895	.36	.41	.46	—	.020	.018	.016	.015	.013	.0293	9500
3000	0.926	.38	.42	.47	—	.019	.017	.016	.014	.012	.0278	9000
3100	0.957	.39	.44	—	—	.018	.016	.015	.013	—	.0262	8500
3200	0.988	.40	.46	—	—	.017	.015	.014	.012	—	.0247	8000
3300	1.019	.42	.47	—	.017	.016	.014	.013	—	—	.0231	7500
3400	1.049	.43	.48	—	.016	.015	.013	.012	—	—	.0216	7000
3500	1.080	.44	.49	—	.015	.014	.012	.011	—	—	.0200	6500
3600	1.111	.45	—	—	.014	.013	.011	—	—	—	.0185	6000
3700	1.142	.46	—	—	.013	.012	.011	—	—	—	.0170	5500
3800	1.173	.48	—	.012	.011	.011	.010	—	—	—	.0154	5000
3900	1.204	.49	—	.011	.010	.010	—	—	—	—	.0139	4500
4000	1.235	.50	—	.010	.009	.009	—	—	—	—	.0123	4000
—	—	—	.008	.008	.007	.007	Corrections in in. to be subtracted for height above sea-level in last column and barometer reading in bottom line.				.0092	3000
—	—	.006	.005	.005	.004	—					.0062	2000
—	—	.003	.003	.003	—	—					.0031	1000
												feet.
		30	28	26	24	22	20	18	16	14	$g_1 - g$	Height above sea-level.
		Observed height of barometer in inches.										

REDUCTION OF BAROMETER TO STANDARD GRAVITY *

METRIC MEASURES

From Latitude 0° to 45°, the Correction is to be Subtracted.

Latitude	520	540	560	580	600	620	640	660	680	700	720	740	760	780
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
0	−1.39	−1.45	−1.50	−1.55	−1.61	−1.66	−1.71	−1.77	−1.82	−1.87	−1.93	−1.98	−2.04	−2.09
5	−1.37	−1.42	−1.48	−1.53	−1.58	−1.64	−1.69	−1.74	−1.79	−1.85	−1.90	−1.95	−2.00	−2.06
6	1.36	1.42	1.47	1.52	1.57	1.63	1.68	1.73	1.78	1.83	1.89	1.94	1.99	2.04
7	1.35	1.40	1.46	1.51	1.56	1.61	1.66	1.72	1.77	1.82	1.87	1.92	1.98	2.03
8	1.34	1.39	1.44	1.49	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.91	1.96	2.01
9	1.33	1.38	1.43	1.48	1.53	1.58	1.63	1.68	1.73	1.78	1.84	1.89	1.94	1.99
10	−1.31	−1.36	−1.41	−1.46	−1.51	−1.56	−1.61	−1.66	−1.71	−1.76	−1.81	−1.86	−1.92	−1.97
11	1.29	1.34	1.39	1.44	1.49	1.54	1.59	1.64	1.69	1.74	1.79	1.84	1.89	1.94
12	1.27	1.32	1.37	1.42	1.47	1.52	1.57	1.62	1.67	1.72	1.76	1.81	1.86	1.91
13	1.25	1.30	1.35	1.40	1.45	1.50	1.54	1.59	1.64	1.69	1.74	1.78	1.83	1.88
14	1.23	1.28	1.33	1.38	1.42	1.47	1.52	1.56	1.61	1.66	1.71	1.75	1.80	1.85
15	−1.21	−1.26	−1.30	−1.35	−1.40	−1.44	−1.49	−1.54	−1.58	−1.63	−1.67	−1.72	−1.77	−1.81
16	1.19	1.23	1.28	1.32	1.37	1.41	1.46	1.50	1.55	1.60	1.64	1.69	1.73	1.78
17	1.16	1.20	1.25	1.29	1.34	1.38	1.43	1.47	1.52	1.56	1.60	1.65	1.69	1.74
18	1.13	1.18	1.22	1.26	1.31	1.35	1.39	1.44	1.48	1.52	1.57	1.61	1.65	1.70
19	1.10	1.15	1.19	1.23	1.27	1.32	1.36	1.40	1.44	1.48	1.53	1.57	1.61	1.65
20	−1.07	−1.11	−1.16	−1.20	−1.24	−1.28	−1.32	−1.36	−1.40	−1.44	−1.49	−1.53	−1.57	−1.61
21	1.04	1.08	1.12	1.16	1.20	1.24	1.28	1.32	1.36	1.40	1.44	1.48	1.52	1.56
22	1.01	1.05	1.09	1.13	1.16	1.20	1.24	1.28	1.32	1.36	1.40	1.44	1.48	1.51
23	0.98	1.01	1.05	1.09	1.13	1.16	1.20	1.24	1.28	1.31	1.35	1.39	1.43	1.46
24	0.94	0.98	1.01	1.05	1.08	1.12	1.16	1.19	1.23	1.27	1.30	1.34	1.37	1.41
25	−0.90	−0.94	−0.97	−1.01	−1.04	−1.08	−1.11	−1.15	−1.18	−1.22	−1.25	−1.29	−1.32	−1.36
26	0.87	0.90	0.93	0.97	1.00	1.03	1.07	1.10	1.13	1.17	1.20	1.23	1.27	1.30
27	0.83	0.86	0.89	0.92	0.96	0.99	1.02	1.05	1.08	1.12	1.15	1.18	1.21	1.24
28	0.79	0.82	0.85	0.88	0.91	0.94	0.97	1.00	1.03	1.06	1.09	1.12	1.15	1.18
29	0.75	0.78	0.81	0.84	0.86	0.89	0.92	0.95	0.98	1.01	1.04	1.07	1.10	1.12
30	−0.71	−0.74	−0.76	−0.79	−0.82	−0.85	−0.87	−0.90	−0.93	−0.95	−0.98	−1.01	−1.04	−1.06
31	0.67	0.69	0.72	0.74	0.77	0.80	0.82	0.85	0.87	0.90	0.92	0.95	0.98	1.00
32	0.62	0.65	0.67	0.70	0.72	9.74	0.77	0.79	0.82	0.84	0.86	0.89	0.91	0.94
33	0.58	0.60	0.63	0.65	0.67	0.69	0.72	0.74	0.76	0.78	0.80	0.83	0.85	0.87
34	0.54	0.56	0.58	0.60	0.62	0.64	0.66	0.68	0.70	0.72	0.74	0.76	0.79	0.81
35	−0.49	−0.51	−0.53	−0.55	−0.57	−0.59	−0.61	−0.63	−0.64	−0.66	−0.68	−0.70	−0.72	−0.74
36	0.45	0.46	0.48	0.50	0.52	0.53	0.55	0.57	0.58	0.60	0.62	0.64	0.65	0.67
37	0.40	0.42	0.43	0.45	0.46	0.48	0.49	0.51	0.52	0.54	0.56	0.57	0.59	0.60
38	0.36	0.37	0.38	0.40	0.41	0.42	0.44	0.45	0.46	0.48	0.49	0.51	0.52	0.53
39	0.31	0.32	0.33	0.34	0.36	0.37	0.38	0.39	0.40	0.42	0.43	0.44	0.45	0.46
40	−0.26	−0.27	−0.28	−0.29	−0.30	−0.31	−0.32	−0.33	−0.34	−0.35	−0.36	−0.37	−0.38	−0.39
41	0.21	0.22	0.23	0.24	0.25	0.26	0.26	0.27	0.28	0.29	0.30	0.30	0.31	0.32
42	0.17	0.17	0.18	0.19	0.19	0.20	0.21	0.21	0.22	0.22	0.23	0.24	0.24	0.25
43	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.16	0.16	0.16	0.17	0.17	0.18
44	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.11
45	−0.02	−0.02	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.04

* "Smithsonian Meteorological Tables."

REDUCTION OF BAROMETER TO STANDARD GRAVITY *

METRIC MEASURES

From Latitude 46° to 90°, the Correction is to be Added.

Latitude	520	540	560	580	600	620	640	660	680	700	720	740	760	780
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
45	−0.02	−0.02	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.03	−0.04
46	+0.02	+0.03	+0.03	+0.03	+0.03	+0.03	+0.03	+0.03	+0.03	+0.03	+0.03	+0.03	+0.04	+0.04
47	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.11
48	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.16	0.16	0.17	0.17	0.18	0.18
49	0.17	0.17	0.18	0.19	0.19	0.20	0.21	0.21	0.22	0.23	0.23	0.24	0.25	0.25
50	0.22	0.22	0.23	0.24	0.25	0.26	0.26	0.27	0.28	0.29	0.30	0.31	0.31	0.32
51	+0.26	+0.27	+0.28	+0.29	+0.30	+0.31	+0.32	+0.33	+0.34	+0.35	+0.36	+0.37	+0.38	+0.39
52	0.31	0.32	0.33	0.34	0.36	0.37	0.38	0.39	0.40	0.42	0.43	0.44	0.45	0.46
53	0.36	0.37	0.38	0.40	0.41	0.42	0.44	0.45	0.46	0.48	0.49	0.51	0.52	0.53
54	0.40	0.42	0.43	0.45	0.46	0.48	0.49	0.51	0.52	0.54	0.56	.057	0.59	0.60
55	0.45	0.46	0.48	0.50	0.52	0.53	0.55	0.57	0.58	0.60	0.62	0.64	0.65	0.67
56	+0.49	+0.51	+0.53	+0.55	+0.57	+0.59	+0.60	+0.62	+0.64	+0.66	+0.68	+0.70	+0.72	+0.74
57	0.54	0.56	0.58	0.60	0.62	0.64	0.66	0.68	0.70	0.72	0.74	0.76	0.78	0.80
58	0.58	0.60	0.62	0.65	0.67	0.69	0.71	0.74	0.76	0.78	0.80	0.82	0.85	0.87
59	0.62	0.65	0.67	0.69	0.72	0.74	0.77	0.79	0.81	0.84	0.86	0.89	0.91	0.93
60	0.66	0.69	0.72	0.74	0.77	0.79	0.82	0.84	0.87	0.89	0.92	0.94	0.97	1.00
61	+0.71	+0.73	+0.76	+0.79	+0.81	+0.84	+0.87	+0.89	+0.92	+0.95	+0.98	+1.00	+1.03	+1.06
62	0.74	0.77	0.80	0.83	0.85	0.88	0.91	0.94	0.97	1.00	1.02	1.05	1.08	1.11
63	0.78	0.81	0.85	0.88	0.91	0.94	0.97	1.00	1.03	1.06	1.09	1.12	1.15	1.18
64	0.82	0.85	0.89	0.92	0.95	0.98	1.01	1.04	1.08	1.11	1.14	1.17	1.20	1.23
65	0.86	0.89	0.93	0.96	0.99	1.03	1.06	1.09	1.13	1.16	1.19	1.22	1.26	1.29
66	+0.90	+0.93	+0.97	+1.00	+1.04	+1.07	+1.10	+1.14	+1.17	+1.21	+1.24	+1.28	+1.31	+1.35
67	0.93	0.97	1.00	1.04	1.08	1.11	1.15	1.18	1.22	1.25	1.29	1.33	1.36	1.40
68	0.97	1.00	1.04	1.08	1.11	1.15	1.19	1.23	1.26	1.30	1.34	1.37	1.41	1.45
69	1.00	1.04	1.08	1.11	1.15	1.19	1.23	1.27	1.31	1.34	1.38	1.42	1.46	1.50
70	1.03	1.07	1.11	1.15	1.19	1.23	1.27	1.31	1.35	1.39	1.43	1.47	1.51	1.55
71	+1.06	+1.10	+1.14	+1.18	+1.22	+1.26	+1.31	+1.35	+1.39	+1.43	+1.47	+1.51	+1.55	+1.59
72	1.09	1.13	1.17	1.22	1.26	1.30	1.34	1.38	1.42	1.47	1.51	1.55	1.59	1.63
73	1.12	1.16	1.20	1.25	1.29	1.33	1.37	1.42	1.46	1.50	1.55	1.59	1.63	1.67
74	1.14	1.19	1.23	1.28	1.32	1.36	1.41	1.45	1.50	1.54	1.58	1.63	1.67	1.72
75	1.17	1.21	1.26	1.30	1.35	1.39	1.44	1.48	1.53	1.57	1.62	1.66	1.71	1.75
76	+1.19	+1.24	+1.28	+1.33	+1.37	+1.42	+1.47	+1.51	+1.56	+1.60	+1.65	+1.70	+1.74	+1.79
77	1.21	1.26	1.31	1.35	1.40	1.45	1.49	1.54	1.59	1.63	1.68	1.73	1.77	1.82
78	1.23	1.28	1.33	1.38	1.42	1.47	1.52	1.57	1.61	1.66	1.71	1.76	1.80	1.85
79	1.25	1.30	1.35	1.40	1.45	1.49	1.54	1.59	1.64	1.69	1.73	1.78	1.83	1.88
80	1.27	1.32	1.37	1.42	1.47	1.51	1.56	1.61	1.66	1.71	1.76	1.81	1.86	1.90
81	+1.29	+1.33	+1.38	+1.43	+1.48	+1.53	+1.58	+1.63	+1.68	+1.73	+1.78	+1.83	+1.88	+1.93
82	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95
83	1.31	1.36	1.41	1.46	1.51	1.56	1.61	1.67	1.72	1.77	1.82	1.87	1.92	1.97
84	1.32	1.37	1.42	1.48	1.53	1.58	1.63	1.68	1.73	1.78	1.83	1.88	1.93	1.98
85	1.33	1.38	1.43	1.49	1.54	1.59	1.64	1.69	1.74	1.79	1.84	1.90	1.95	2.00
90	+1.35	+1.41	+1.46	+1.51	+1.56	+1.61	+1.67	+1.72	+1.77	+1.82	+1.87	+1.93	+1.98	+2.03

* "Smithsonian Meteorological Tables."

REDUCTION OF BAROMETER TO STANDARD GRAVITY *

ENGLISH MEASURES

From Latitude 0° to 45°, the Correction is to be Subtracted.

Latitude	19	20	21	22	23	24	25	26	27	28	29	30
	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
0	−0.051	−0.054	−0.056	−0.059	−0.062	−0.064	−0.067	−0.070	−0.072	−0.075	−0.078	−0.080
5	−0.050	−0.053	−0.055	−0.058	−0.061	−0.063	−0.066	−0.069	−0.071	−0.074	−0.077	−0.079
6	0.050	0.052	0.055	0.058	0.060	0.063	0.066	0.068	0.071	0.073	0.076	0.079
7	0.049	0.052	0.055	0.057	0.060	0.062	0.065	0.068	0.070	0.073	0.075	0.078
8	0.049	0.052	0.054	0.057	0.059	0.062	0.064	0.067	0.070	0.072	0.075	0.077
9	0.048	0.051	0.054	0.056	0.059	0.061	0.064	0.066	0.069	0.071	0.074	0.076
10	−0.048	−0.050	−0.053	−0.055	−0.058	−0.060	−0.063	−0.066	−0.068	−0.071	−0.073	−0.076
11	0.047	0.050	0.052	0.055	0.057	0.060	0.062	0.065	0.067	0.070	0.072	0.075
12	0.047	0.049	0.051	0.054	0.056	0.059	0.061	0.064	0.066	0.069	0.071	0.074
13	0.046	0.048	0.051	0.053	0.055	0.058	0.060	0.063	0.065	0.068	0.070	0.072
14	0.045	0.047	0.050	0.052	0.055	0.057	0.059	0.062	0.064	0.066	0.069	0.071
15	−0.044	−0.047	−0.049	−0.051	−0.053	−0.056	−0.058	−0.060	−0.063	−0.065	−0.067	−0.070
16	0.043	0.046	0.048	0.050	0.052	0.055	0.057	0.059	0.062	0.064	0.066	0.068
17	0.042	0.045	0.047	0.049	0.051	0.053	0.056	0.058	0.060	0.062	0.065	0.067
18	0.041	0.044	0.046	0.048	0.050	0.052	0.054	0.057	0.059	0.061	0.063	0.065
19	0.040	0.042	0.045	0.047	0.049	0.051	0.053	0.055	0.057	0.059	0.062	0.064
20	−0.039	−0.041	−0.043	−0.045	−0.047	−0.050	−0.052	−0.054	−0.056	−0.058	−0.060	−0.062
21	0.038	0.040	0.042	0.044	0.046	0.048	0.050	0.052	0.054	0.056	0.058	0.060
22	0.037	0.039	0.041	0.043	0.045	0.047	0.049	0.050	0.052	0.054	0.056	0.058
23	0.036	0.038	0.039	0.041	0.043	0.045	0.047	0.049	0.051	0.053	0.054	0.056
24	0.034	0.036	0.038	0.040	0.042	0.043	0.045	0.047	0.049	0.051	0.052	0.054
25	−0.033	−0.035	−0.037	−0.038	−0.040	−0.042	−0.043	−0.045	−0.047	−0.049	−0.050	−0.052
26	0.032	0.033	0.035	0.037	0.038	0.040	0.042	0.043	0.045	0.047	0.048	0.050
27	0.030	0.032	0.033	0.035	0.037	0.038	0.040	0.041	0.043	0.045	0.046	0.048
28	0.029	0.030	0.032	0.033	0.035	0.036	0.038	0.039	0.041	0.043	0.044	0.046
29	0.027	0.029	0.030	0.032	0.033	0.035	0.036	0.037	0.039	0.040	0.042	0.043
30	−0.026	−0.027	−0.029	−0.030	−0.031	−0.033	−0.034	−0.035	−0.037	−0.038	−0.040	−0.041
31	0.024	0.026	0.027	0.028	0.030	0.031	0.032	0.033	0.035	0.036	0.037	0.038
32	0.023	0.024	0.025	0.026	0.028	0.029	0.030	0.031	0.032	0.034	0.035	0.036
33	0.021	0.022	0.023	0.025	0.026	0.027	0.028	0.029	0.030	0.031	0.032	0.034
34	0.020	0.021	0.022	0.023	0.024	0.025	0.026	0.027	0.028	0.029	0.030	0.031
35	−0.018	−0.019	−0.020	−0.021	−0.022	−0.023	−0.024	−0.025	−0.026	−0.027	−0.027	−0.028
36	0.016	0.017	0.018	0.019	0.020	0.021	0.022	0.022	0.023	0.024	0.025	0.026
37	0.015	0.015	0.016	0.017	0.018	0.019	0.019	0.020	0.021	0.022	0.022	0.023
38	0.013	0.014	0.014	0.015	0.016	0.016	0.017	0.018	0.018	0.019	0.020	0.020
39	0.011	0.012	0.012	0.013	0.014	0.014	0.015	0.015	0.016	0.017	0.017	0.018
40	−0.010	−0.010	−0.011	−0.011	−0.012	−0.012	−0.013	−0.013	−0.014	−0.014	−0.015	−0.015
41	0.008	0.008	0.009	0.009	0.009	0.010	0.010	0.011	0.011	0.012	0.012	0.012
42	0.006	0.006	0.007	0.007	0.007	0.008	0.008	0.008	0.009	0.009	0.009	0.010
43	0.004	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.006	0.007	0.007
44	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.004	0.004	0.004
45	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001

* "Smithsonian Meteorological Tables."

REDUCTION OF BAROMETER TO STANDARD GRAVITY *

ENGLISH MEASURES

From Latitude 46° to 90° the Correction is to be Added.

Latitude	19	20	21	22	23	24	25	26	27	28	29	30
	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
45	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001	−0.001
46	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001
47	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.004	0.004	0.004
48	0.004	0.005	0.005	0.005	0.005	c.006	0.006	0.006	0.006	0.006	0.007	0.007
49	0.006	0.006	0.007	0.007	0.007	0.008	0.008	0.008	0.009	0.009	0.009	0.010
50	0.008	0.008	0.009	0.009	0.010	0.010	0.010	0.011	0.011	0.012	0.012	0.012
51	+0.010	+0.010	+0.011	+0.011	+0.012	+0.012	+0.013	+0.013	+0.014	+0.014	+0.015	+0.015
52	0.011	0.012	0.012	0.013	0.014	0.014	0.015	0.015	0.016	0.016	0.017	0.018
53	0.013	0.014	0.014	0.015	0.016	0.016	0.017	0.018	0.018	0.019	0.020	0.020
54	0.015	0.015	0.016	0.017	0.018	0.019	0.019	0.020	0.021	0.022	0.022	0.023
55	0.016	0.017	0.018	0.019	0.020	0.021	0.021	0.022	0.023	0.024	0.025	0.026
56	+0.018	+0.019	+0.020	+0.021	+0.022	+0.023	+0.024	+0.024	+0.026	+0.026	+0.027	+0.028
57	0.020	0.021	0.022	0.023	0.024	0.025	0.026	0.027	0.028	0.029	0.030	0.031
58	0.021	0.022	0.023	0.025	0.026	0.027	0.028	0.029	0.030	0.031	0.032	0.033
59	0.023	0.024	0.025	0.026	0.028	0.029	0.030	0.031	0.032	0.033	0.035	0.036
60	0.024	0.026	0.027	0.028	0.029	0.031	0.032	0.033	0.034	0.036	0.037	0.038
61	+0.026	+0.027	+0.028	+0.030	+0.031	+0.033	+0.034	+0.035	+0.037	+0.038	+0.039	+0.041
62	0.027	0.029	0.030	0.032	0.033	0.034	0.036	0.037	0.039	0.040	0.042	0.043
63	0.029	0.030	0.032	0.033	0.035	0.036	0.038	0.039	0.041	0.042	0.044	0.045
64	0.030	0.032	0.033	0.035	0.036	0.038	0.040	0.041	0.043	0.044	0.046	0.047
65	0.031	0.033	0.035	0.036	0.038	0.040	0.041	0.043	0.045	0.046	0.048	0.050
66	+0.033	+0.034	+0.036	+0.038	+0.040	+0.041	+0.043	+0.045	+0.047	+0.048	+0.050	+0.052
67	0.034	0.036	0.038	0.039	0.041	0.043	0.045	0.047	0.048	0.050	0.052	0.054
68	0.035	0.037	0.039	0.041	0.043	0.045	0.046	0.048	0.050	0.052	0.054	0.056
69	0.036	0.038	0.040	0.042	0.044	0.046	0.048	0.050	0.052	0.054	0.056	0.058
70	0.038	0.040	0.042	0.044	0.046	0.048	0.050	0.052	0.053	0.055	0.057	0.059
71	+0.039	+0.041	+0.043	+0.045	+0.047	+0.049	+0.051	+0.053	+0.055	+0.057	+0.059	+0.061
72	0.040	0.042	0.044	0.046	0.048	0.050	0.052	0.054	0.057	0.059	0.061	0.063
73	0.041	9.043	0.045	0.047	0.049	0.052	0.054	0.056	0.058	0.060	0.062	0.064
74	0.042	0.044	0.046	0.048	0.051	0.053	0.055	0.057	0.059	0.062	0.064	0.066
75	0.043	0.045	0.047	0.049	0.052	0.054	0.056	0.058	0.061	0.063	0.065	0.067
76	+0.044	+0.046	+0.048	+0.050	+0.053	+0.055	+0.057	+0.060	+0.062	+0.064	0.066	0.069
77	0.044	0.047	0.049	0.051	0.054	0.056	0.058	0.061	0.063	0.065	0.068	0.070
78	0.045	0.047	0.050	0.052	0.055	0.057	0.059	0.062	0.064	0.066	0.069	0.071
79	0.046	0.048	0.051	0.053	0.055	0.058	0.060	0.063	0.065	0.067	0.070	0.072
80	0.046	0.049	0.051	0.054	0.056	0.059	0.061	0.063	0.066	0.068	0.071	0.073
81	+0.047	+0.049	+0.052	+0.054	+0.057	+0.059	+0.062	+0.064	+0.067	+0.069	+0.072	+0.074
82	0.047	0.050	0.052	0.055	0.057	0.060	0.062	0.065	0.067	0.070	0.072	0.075
83	0.048	0.050	0.053	0.056	0.058	0.061	0.063	0.066	0.068	0.071	0.073	0.076
84	0.048	0.051	0.053	0.056	0.059	0.061	0.064	0.066	0.069	0.071	0.074	0.076
85	0.049	0.051	0.054	0.056	0.059	0.061	0.064	0.067	0.069	0.072	0.074	0.077
90	+0.049	+0.052	+0.055	+0.057	+0.060	+0.062	+0.065	+0.068	+0.070	+0.073	+0.075	+0.078

* "Smithsonian Meteorological Tables."

TABLE 137.—Correction of the Barometer for Capillarity *

1. Metric Measure.

Diameter of tube in mm.	Height of Meniscus in Millimeters.							
	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8
	Correction to be added in millimeters.							
4	0.83	1.22	1.54	1.98	2.37	–	–	–
5	.47	0.65	0.86	1.19	1.45	1.80	–	–
6	.27	.41	.56	0.78	0.98	1.21	1.43	–
7	.18	.28	.40	.53	.67	0.82	0.97	1.13
8	–	.20	.29	.38	.46	.56	.65	0.77
9	–	.15	.21	.28	.33	.40	.46	.52
10	–	–	.15	.20	.25	.29	.33	.37
11	–	–	.10	.14	.18	.21	.24	.27
12	–	–	.07	.10	.13	.15	.18	.19
13	–	–	.04	.07	.10	.12	.13	.14

2. British Measure.

Diameter of tube in inches.	Height of Meniscus in Inches.							
	.01	.02	.03	.04	.05	.06	.07	.08
	Correction to be added in inches.							
.15	0.024	0.047	0.069	0.092	0.116	–	–	–
.20	.011	.022	.033	.045	.059	0.078	–	–
.25	.006	.012	.019	.028	.037	.047	0.059	–
.30	.004	.008	.013	.018	.023	.029	.035	0.042
.35	–	.005	.008	.012	.015	.018	.022	.026
.40	–	.004	.006	.008	.010	.012	.014	.016
.45	–	–	.003	.005	.007	.008	.010	.012
.50	–	–	.002	.004	.005	.006	.006	.007
.55	–	–	.001	.002	.003	.004	.005	.005

* The first table is from Kohlrausch (Experimental Physics), and is based on the experiments of Mendelejeff and Gutkowski (Jour. de Phys. Chem. Geo. Petersburg, 1877, or Wied. Beib. 1877). The second table has been calculated from the same data by conversion into inches and graphic interpolation.

TABLE 138.—Volume of Mercury Meniscus in Cu. Mm

Height of meniscus.	Diameter of tube in mm										
	14	15	16	17	18	19	20	21	22	23	24
mm											
1.6	157	185	214	245	280	318	356	398	444	492	541
1.8	181	211	244	281	320	362	407	455	507	560	616
2.0	206	240	278	319	362	409	460	513	571	631	694
2.2	233	271	313	358	406	459	515	574	637	704	776
2.4	262	303	350	400	454	511	573	639	708	781	859
2.6	291	338	388	444	503	565	633	706	782	862	948

Scheel und Heuse, Annalen der Physik, 33, p. 291, 1910.

TABLE 139

PRESSURES AND THE BOILING POINT OF WATER

Useful when a boiling-point apparatus is used in the determination of heights.

(A) METRIC UNITS.

Temperature.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
C	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
80°	355.40	356.84	358.28	359.73	361.19	362.65	364.11	365.58	367.06	368.54
81	370.03	371.52	373.01	374.51	376.02	377.53	379.05	380.57	382.09	383.62
82	385.16	386.70	388.25	389.80	391.36	392.92	394.49	396.06	397.64	399.22
83	400.81	402.40	404.00	405.61	407.22	408.83	410.45	412.08	413.71	415.35
84	416.99	418.64	420.29	421.95	423.61	425.28	426.95	428.64	430.32	432.01
85	433.71	435.41	437.12	438.83	440.55	442.28	444.01	445.75	447.49	449.24
86	450.99	452.75	454.51	456.28	458.06	459.84	461.63	463.42	465.22	467.03
87	468.84	470.66	472.48	474.31	476.14	477.99	479.83	481.68	483.54	485.41
88	487.28	489.16	491.04	492.93	494.82	496.72	498.63	500.54	502.46	504.39
89	506.32	508.26	510.20	512.15	514.11	516.07	518.04	520.01	521.99	523.98
90	525.97	527.97	529.98	531.99	534.01	536.04	538.07	540.11	542.15	544.21
91	546.26	548.33	550.40	552.48	554.56	556.65	558.75	560.85	562.96	565.08
92	567.20	569.33	571.47	573.61	575.76	577.92	580.08	582.25	584.43	586.61
93	588.80	591.00	593.20	595.41	597.63	599.86	602.09	604.33	606.57	608.82
94	611.08	613.35	615.62	617.90	620.19	622.48	624.79	627.09	629.41	631.73
95	634.06	636.40	638.74	641.09	643.45	645.82	648.19	650.57	652.96	655.35
96	657.75	660.16	662.58	665.00	667.43	669.87	672.32	674.77	677.23	679.70
97	682.18	684.66	687.15	689.65	692.15	694.67	697.19	699.71	702.25	704.79
98	707.35	709.90	712.47	715.04	717.63	720.22	722.81	725.42	728.03	730.65
99	733.28	635.92	738.56	741.21	743.87	740.54	749.22	751.90	754.59	757.29
100	760.00	762.72	765.44	768.17	770.91	773.66	776.42	779.18	781.95	784.73

(B) ENGLISH UNITS.

Temperature.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
F.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
185°	17.075	17.112	17.150	17.187	17.224	17.262	17.300	17.337	17.375	17.413
186	17.450	17.488	17.526	17.564	17.602	17.641	17.679	17.717	17.756	17.794
187	17.832	17.871	17.910	17.948	17.987	18.026	18.065	18.104	18.143	18.182
188	18.221	18.261	18.300	18.340	18.379	18.419	18.458	18.498	18.538	18.578
189	18.618	18.658	18.698	18.738	18.778	18.818	18.859	18.899	18.940	18.980
190	19.021	19.062	19.102	19.143	19.184	19.225	19.266	19.308	19.349	19.390
191	19.431	19.473	19.514	19.556	19.598	19.639	19.681	19.723	19.765	19.807
192	19.849	19.892	19.934	19.976	20.019	20.061	20.104	20.146	20.189	20.232
193	20.275	20.318	20.361	20.404	20.447	20.490	20.533	20.577	20.620	20.664
194	20.707	20.751	20.795	20.839	20.883	20.927	20.971	21.015	21.059	21.103
195	21.148	21.192	21.237	21.282	21.326	21.371	21.416	21.461	21.506	21.551
196	21.597	21.642	21.687	21.733	21.778	21.824	21.870	21.915	21.961	22.007
197	22.053	22.099	22.145	22.192	22.238	22.284	22.331	22.377	22.424	22.471
198	22.517	22.564	22.611	22.658	22.706	22.752	22.800	22.847	22.895	22.942
199	22.990	23.038	23.085	23.133	23.181	23.229	23.277	23.325	23.374	23.422
200	23.470	23.519	23.568	23.616	23.665	23.714	23.763	23.812	23.861	23.910
201	23.959	24.009	24.058	24.108	24.157	24.207	24.257	24.307	24.357	24.407
202	24.457	24.507	24.557	24.608	24.658	24.709	24.759	24.810	24.861	24.912
203	24.963	25.014	25.065	25.116	25.168	25.219	25.271	25.322	25.374	25.426
204	25.478	25.530	25.582	25.634	25.686	25.738	25.791	25.843	25.896	25.948
205	26.001	26.054	26.107	26.160	26.213	26.266	26.319	26.373	26.426	26.480
206	26.534	26.587	26.641	26.695	26.749	26.803	26.857	26.912	26.966	27.021
207	27.075	27.130	27.184	27.239	27.294	27.349	27.404	27.460	27.515	27.570
208	27.626	27.681	27.737	27.793	27.848	27.904	27.960	28.016	28.073	28.129
209	28.185	28.242	28.298	28.355	28.412	28.469	28.526	28.583	28.640	28.697
210	28.754	28.812	28.869	28.927	28.985	29.042	29.100	29.158	29.216	29.275
211	29.333	29.391	29.450	29.508	29.567	29.626	29.685	29.744	29.803	29.862
212	29.921	29.981	30.040	30.100	30.159	30.219	30.279	30.339	30.399	30.459
213	30.519	30.580	30.640	30.701	30.761	30.822	30.883	30.944	31.005	31.066
214	31.127	31.199	31.250	31.311	31.373	31.435	31.497	31.559	31.621	31.683

DETERMINATION OF HEIGHTS BY THE BAROMETER

Formula of Babinet: $Z = C \frac{B_0 - B}{B_0 + B}$.

C (in feet) $= 52494 \left[1 + \frac{t_0 + t - 64}{900}\right]$ English measures.

C (in meters) $= 16000 \left[1 + \frac{2(t_0 + t)}{1000}\right]$ metric measures.

In which Z = difference of height of two stations in feet or meters.

B_0, B = barometric readings at the lower and upper stations respectively, corrected for all sources of instrumental error.

t_0, t = air temperatures at the lower and upper stations respectively.

Values of C

English Measures.			Metric Measures.		
$\frac{1}{2}(t_0 + t)$.	C	Log C	$\frac{1}{2}(t_0 + t)$.	C	Log C
Fahr.	Feet.		Cent.	Meters.	
10°	49928	4.69834	**—10°**	15360	4.18639
15	50511	.70339	—8	15488	.19000
			—6	15616	.19357
20	51094	4.70837	—4	15744	.19712
25	51677	.71330	—2	15872	.20063
30	52261	4.71818	**0**	16000	4.20412
35	52844	.72300	+ 2	16128	.20758
			4	16256	.21101
40	53428	4.72777	6	16384	.21442
45	54011	.73248	8	16512	.21780
50	54595	4.73715	**10**	16640	4.22115
55	55178	.74177	12	16768	.22448
			14	16896	.22778
60	55761	4.74633	16	17024	.23106
65	56344	.75085	18	17152	.23431
70	56927	4.75532	**20**	17280	4.23754
75	57511	.75975	22	17408	.24075
			24	17536	.24393
80	58094	4.76413	26	17664	.24709
85	58677	.76847	28	17792	.25022
90	59260	4.77276	**30**	17920	4.25334
95	59844	.77702	32	18048	.25643
			34	18176	.25950
100	60427	4.78123	36	18304	.26255

Values only approximate. Not good for great altitudes. A more accurate formula with corresponding tables may be found in Smithsonian Meteorological Tables.

TABLES 141 AND 142

VELOCITY OF SOUND

TABLE 141.—Velocity of Sound in Solids

The velocity of sounds in solids varies as $\sqrt{E/\rho}$, where E is Young's modulus of elasticity and ρ the density. These constants for most materials vary through a somewhat wide range. The numbers can be taken only as rough approximations to the velocity in any particular case. When temperatures are not marked, between 10° and 20° is to be understood.

Substance	t°C	v m/sec.	Ref.	Substance	t°C	v m/sec.	Ref.
Ag hard	20	2678	2	Fe	200	4720	2
" "	100	2640	2	"	20	4990	3
" "	200	2480	2	"	100	4920	3
Al		5104	1	"	200	4790	3
Au hard	20	1743	2	Mg		4602	4
" "	100	1720	2	Ni		4973	1
Cd		2307	1	Pb		1322	1
Co	·	4724	1	Pd		3150	
Cu	20	3560	2	Pt	20	2690	2
"	100	3290	2	"	100	2570	2
"	200	2950	2	"	200	2460	2
Fe	20	5130	2	Sn		2500	
"	100	5300	2	Zn		3700	
Ash, along the fiber		4670	2	Brick		3652	5
" across the rings		1390	2	Clay rock		3480	6
" along the rings		1260	2	Cork		500	7
Beech, along the fiber		3340	2	Granite		3950	6
" across the rings		1840	2	Marble		3810	6
" along the rings		1415	2	Paraffin	15	1304	8
Elm, along the fiber		4120	2	Slate		4510	6
" across the rings		1420	2	Tallow	16	390	8
" along the rings		1013	2	Tuff		2850	6
Fir, along the fiber		4640	2	Glass { from		5000	
Mahogany, along the				Glass { to		6000	
fiber		4135	3	Ivory		3013	9
Maple, along the fiber		4110	2	Vul. rubber (black)	0	54	10
Oak, along the fiber		3850	2	Vul. rubber (black)	50	31	10
Pine, along the fiber		3320	2	" " (red)	0	69	10
Poplar, along the fiber		4280	2	" " "	70	34	10
Sycamore, along the				Wax	17	880	7
fiber		4460	2	"	28	441	7

(1) Masson. (2) Wertheim. (3) Cast steel, Wertheim. (4) Melde. (5) Chladni. (6) Gray & Milne. (7) Stefan. 8) Warburg. (9) Ciccone & Campanile. (10) Exner.

TABLE 142.—Velocity of Sound in Water

Substance	t°C	v m/sec.	Ref.	Substance	t°C	v m/sec.	Ref.
Water, air-free	13	1441	1	Water, sea: (continued)			
" dust-free	19	1461	1	Seine River	60	1724	5
" " "	31	1505	1	N. Atlantic,			
" distilled	20	1470	2	1228m deep		1520	6
" 10% Na Cl sol.	15	1470	1	Carib. Sea,			
" 15% Na Cl sol.	15	1530	1	338m deep		1478	6
" 20% Na Cl sol.	15	1650	1	Carib. Sea,			
Water, sea:				1771m deep		1486	6
35.1% salt	6	1474	3	Pacific, 2962m deep		1493	6
35.2% "	7	1477.4	3	Explosive Waves:			
35% "	17	1510.4	3	Gun Cotton, 9 oz.		1732	7
Lake Geneva	9	1435	4	" " 10 "		1775	7
Seine River	15	1437	5	" " 18 "		1942	7
" "	30	1528	5	" " 64 "		2013	7

(1) Dörsing, 1908. (2) Ionescu, 1924. (3) Wood, Browne, Cochran, 1923. (4) Colladon-Sturm. (5) Wertheim. (6) Heck & Service, 1924. (7) Threlfall, Adair, 1889, see Barstow's Sound, p. 518.

TABLE 143

VELOCITY OF SOUND IN LIQUIDS AND GASES

For gases, the velocity of sound = $\sqrt{\gamma P/\rho}$, where P is the pressure, ρ the density, and γ the ratio of specific heat at constant pressure to that at constant volume. For moderate temperature changes $V_t = V_0(1 + \alpha t)$ where $\alpha = 0.00367$. The velocity of sound in tubes increases with the diameter up to the free-air value as a limit. The values from ammonia to methane inclusive, except for argon and helium, are for closed tubes.

Substance	Temp. C	m/sec.	ft./sec.	Authority
Liquids: Alcohol, 93% Ethyl	18°	1150	3772	Cisman, 1926
" Methyl	19	1143	3750	Busse, 1924
Ammonia, .880	16	1663	5456	Dörsing, 1908
Benzol	17	1166	3826	"
Carbon bisulphide	18	1060	3477	Cisman, 1926
Chloroform	15	983	3225	Dörsing, 1908
Ether	0		3386	Mean
Mercury	20	1407	4614	Bungetziam
Turpentine oil	15	1326	4351	Dörsing, 1908
Gases: Air, dry, 1 atmosphere	0	331.7	1088	Mean
" " 25 "	0	332.0	1089	" (Witkowski)
" " 50 "	0	334.7	1098	" "
" " 100 "	0	350.6	1150	" "
" "	100	386	1266	Stevens
" "	500	553	1814	"
" "	1000	700	2297	"
Ammonia	0	415	1361	Masson
Argon	0	308	1010	Mean
"	1000	666	2184	D, C, P, 1921
Carbon monoxide	0	337.1	1106	Wullner
" "	0	337.4	1107	Dulong
" dioxide	0	258.0	846	Brockendahl, 1906
" disulphide	0	189	620	Masson
Chlorine	0	206.4	677	Martini
"	0	205.3	674	Strecker
Ethylene	0	314	1030	Dulong
Helium	0	971	3185	Scheel, Heuse, 1919
Hydrogen	0	1269.5	4165	Dulong
"	0	1286.4	4221	Zoch
Illuminating gas	0	490.4	1609	"
Methane	0	432	1417	Masson
Nitric oxide	0	325	1066	"
Nitrogen	0	337.8	1108	Mean
Nitrous oxide	0	261.8	859	Dulong
Oxygen	0	317.2	1041	"
Explosive waves in air:				
Charge of powder, 0.24 gms.		336	1102	Violle, Cong. Intern. Phys. 1, 243, 1900
" " " 3.80 "		500	1640	
" " " 17.40 "		931	3060	
" " " 45.60 "		1268	4160	
Vapors: Alcohol	0	230.6	756	Masson
Ether	0	179.2	588	"
Water	0	401	1315	"
"	100	404.8	1328	Treitz, 1903

Supersonics: Reid, 1930:—Air, 0°C, no CO_2, 42 Kc/sec., 331.75 m/sec.; 20°C, sat. H_2O, 333.1 m/sec.; 140 Kc/sec. 331.60, 332.92, respectively; Thompson, 1930:—109 c/sec. sat. H_2O vapor, 27°C, 432 m/sec.; Poole, 1930:—Water, distilled, audio-frequency, 25°C, 1485 m/sec.

MUSICAL SCALES

The pitch relations between two notes may be expressed precisely (1) by the ratio of their vibration frequencies; (2) by the number of equally-tempered semitones between them (E. S.); also, less conveniently, (3) by the common logarithm of the ratio in (1); (4) by the lengths of the two portions of the tense string which will furnish the notes; and (5) in terms of the octave as unity. The ratio in (4) is the reciprocal of that in (1); the number for (5) is 1/12 of that for (2); the number for (2) is nearly 40 times that for (3).

Table 144 gives data for the middle octave, including vibration frequencies for three standards of pitch; $A_3=435$ double vibrations per second, is the international standard and was adopted by the American Piano Manufacturers' Association. The "just-diatonic scale" of C-major is usually deduced, following Chladni, from the ratios of the three perfect major triads reduced to one octave, thus:

		4 : 5 : 6						
4 : 5 :		6		4 : 5 : 6				
F	A	C	E	G	B	D		
16	20	24	30	36	45	54		
		24	27	30	32	36	40	45 48

Other equivalent ratios and their values in E. S. are given in Table 145. By transferring D to the left and using the ratio 10 : 12 : 15 the scale of A-minor is obtained, which agrees with that of C-major except that D=26 2/3. Nearly the same ratios are obtained from a series of harmonics beginning with the eighth; also by taking 12 successive perfect or Pythagorean fifths or fourths and reducing to one octave. Such calculations are most easily made by adding and subtracting intervals expressed in E. S. The notes needed to furnish a just major scale in other keys may be found by successive transpositions by fifths or fourths as shown in Table 145. Disregarding the usually negligible difference of 0.02 E. S., the table gives the 24 notes to the octave required in the simplest enharmonic organ; the notes fall into pairs that differ by a comma, 0.22 E. S. The line "mean tone" is based on Dom Bedos' rule for tuning the organ (1746). The tables have been checked by the data in Ellis' Helmholtz's "Sensations of Tone."

TABLE 144.—Data for Middle Octave

Note.	Interval. Just.	Interval. Tempered.	Ratios. Just.	Ratios. Tempered.	Logarithms. Just.	Logarithms. Tempered.	Number of double Vibrations per second. Just.	Just.	Just.	Tempered.	Tempered.	Tempered
	E. S.	E. S.										
C_3	0.	0	1.00	1.00000	.0000	.00000	256	264	258.7	258.7	261.6	271.1
		1		1.05926		.02509				274.0	277.2	287.3
D_3	2.04	2	1.125	1.12246	.05115	.05017	288	297	291.0	290.3	293.7	304.3
		3		1.18921		.07526				307.6	311.1	322.4
E_3	3.86	4	1.25	1.25992	.09691	.10034	320	330	323.4	325.9	329.6	341.6
F_3	4.98	5	1.33	1.33484	.12494	.12543	341.3	352	344.9	345.3	349.2	361.9
		6		1.41421		.15051				365.8	370.0	383.4
G_3	7.02	7	1.50	1.49831	.17609	.17560	384	396	388	387.5	392.0	406.2
		8		1.58740		20069				410.6	415.3	430.4
A_3	8.84	9	1.67	1.68179	.22185	.22577	426.7	440	431.1	435.0	440.0	456.0
		10		1.78180		.25086				460.9	466.2	483.1
B_3	10.88	11	1.875	1.88775	.27300	.27594	480	495	485.0	488.3	493.9	511.8
C_4	12.00	12	2.00	2.00000	.30103	.30103	512	528	517.3	517.3	523.2	542.3

TABLE 145.—Notes Needed to Transpose to Other Scales

Key of		C		D		E	F		G		A		B	C
7 ♯s	C♯		1.14		3.18		5.00	6.12		8.16		9.98		12.02
			0.92		2.96		4.78	5.90		7.94		9.76		11.80
6 "	F♯		1.14		2.96		5.00	6.12		8.16		9.98	11.10	
			0.92		2.74		4.78	5.90		7.94		9.76	10.88	
5 "	B		1.14		2.96	4.08		6.12		7.94		9.98	11.10	
			0.92		2.74	3.86		5.90		7.72		9.76	10.88	
4 "	E		0.92		2.96	4.08		6.12		7.94	9.06		11.10	
			0.70		2.74	3.86		5.90		7.72	8.84		10.88	
3 "	A		0.92	2.04		4.08		5.90		7.94	9.06		11.10	
			0.70	1.82		3.86		5.68		7.72	8.84		10.88	
2 "	D		0.92	2.04		4.08		5.90	7.02		9.06		10.88	
1 ♯	G	0.00		2.04		3.86		5.90	7.02		9.06		10.88	12.00
	C	0.00		2.04		3.86	4.98		7.02		8.84		10.88	12.00
1 ♭	F	0.00		1.82		3.86	4.98		7.02		8.84	9.96		12.00
2 ♭s	B♭	0.00		1.82	2.94		4.98		6.80		8.84	9.96		12.00
3 "	E♭	−.22		1.82	2.94		4.98		6.80	7.92		9.96		11.78
4 "	A♭	−.22	0.90		2.94		4.76		6.80	7.92		9.96		11.78
5 "	D♭	−.22	0.90		2.94		4.76	5.88		7.92		9.74		11.78
6 "	G♭		0.90		2.72		4.76	5.88		7.92		9.74	10.86	
7 "	C♭		0.90		2.72	3.84		5.88		7.70		9.74	10.86	
Harmonic Series		8 0.0	(17 1.05)	9 2.04	(19 2.98)	10 3.86	(21 4.70)	11 5.51	12 7.02	(25 7.73)	13 8.41	14 9.69	15 10.88	16 12.00
Cycle of fifths		0.0	1.14	2.04	3.18	4.08	5.22	6.12	7.02	8.16	9.06	10.20	11.10	12.24
Cycle of fourths		0.0	0.90	1.80	2.94	3.84	4.98	5.88	6.78	7.92	8.82	9.96	10.86	11.76
Mean tone		0.0	0.76	1.93	3.11	3.86	5.03	5.79	6.97	7.72	8.90	10.07	10.83	12.00
Equal 7 step		0.0		1.71	3.43		5.14		6.86		8.57	10.29		12.00

TABLE 146.—A Fundamental Tone, its Harmonics (Overtones) and the Nearest Tone of the Equal-tempered Scale

No. of partial	1	2	3	4	5	6	7	8	9	10
Frequency	129	259	388	517	647	776	905	1035	1164	1293
Nearest tempered note	C	C	G	C	E	G	Bb	C	D	E
Corresponding frequency	129	259	388	517	652	775	922	1035	1164	1293
No. of partial	11	12	13	14	15	16	17	18	19	20
Frequency	1423	1552	1681	1811	1940	2069	2199	2328	2457	2586
Nearest tempered note	Gb	G	G♯	Bb	B	C	C♯	D	D♯	E
Corresponding frequency	1463	1550	1642	1843	1953	2069	2192	2323	2461	2607

CHARACTERISTICS OF SPEECH, MUSIC, AND NOISE

(See Kaye, Nature 128, 253, 1931; Fletcher, Rev. Mod. Phys., 3, 258, 1931.)

Average ear perceives frequencies 20–20,000 cycles/sec. Upper limit less with increasing age. Ordinarily attention largely restricted to 50–5,000 for speech, 35–7,000 in music.

Matching of sounds.—Average ear detects 10 per cent difference of energy when two notes of medium loudness sound alternately without break; doubled if interval of silence; ordinarily 25 per cent holds.

Weber-Fechner law.—When sound sensation advances arithmetically, physical intensity advances geometrically (Kingsbury). Frequencies, 700–4,000 c/sec., relation between loudness and intensity independent of frequency. Lower frequencies, loudness increases proportionally more rapidly than intensity.

TABLE 147.—The Bel and the Decibel

Bel, Decibel.—One bel is 10-fold increase in power or energy.

Intensities differing as r to 1 differ by log r bels.

Ratio intensities	1	10	100	1,000	10,000	10^{13}	
Number decibels, 10 log r	0	10	20	30	40	130	db

Least perceptible change in loudness of a sound of medium loudness under various conditions = 1 db (0.2 to 9 db according to frequency and loudness). Threshold of audibility taken as zero (see Table 148). Pure sounds of medium frequency: range of audibility between threshold and sensation of "feeling" of the sound about 130 db.

If intensity levels of two pure sounds is the same, then if each is increased by the same amount of energy they no longer give an equal sensation of tone. Standard for mixed sounds may be taken as a pure note. Frequency about 1000 cycles/sec. Threshold value (zero) = about 1 millidyne/cm².

TABLE 148.—Loudness Levels of Various Noises

Source	Distance ft.	Average decibels above threshold	Note	Source	Distance ft.	Average decibels above threshold	Note
Quiet whisper	5	10	6	Lindbergh applause	Street	90	5
Quiet garden	..	30	1	Pneumatic drill	20	90	1
Ordinary talk	3	50	6	Elevated R.R., N.Y.	20	90	3
Express train	Pullman	60	4	N. Y. subway	Int.	95	4
Steamship siren	1,500	60	3	Riveting	35	95	3
Busy traffic, N. Y.	..	72	2	Steamship siren	115	95	3
Police whistle	15	80	3	Airplane cabin	Int.	80–110	..
Lion roaring, Zoo	18	85	3	Airplane engine	18	115	4

(1) Davis, Journ. Roy. Aeron. Soc., 1931. (2) Free. (3) Galt. (4) Parkinson, Journ. Acoust. Soc. Amer., 1930. (5) Fletcher. (6) Kaye.

TABLE 149.—Peak Power in Watts of Musical Instruments (Fortissimo)

(Sivian, Dunn, White, Journ. Acoust. Soc. Amer., Jan. 1931.)

75-piece orchestra	70	Trombone	6	Piccolo	0.08
Large bass drum	25	Piano	0.4	Flute	0.06
Pipe organ	13	Trumpet	0.3	Clarinet	0.05
Snare drum	12	Bass tuba	0.2	French horn	0.05
Cymbals	10	Bass viol	0.16	Triangle	0.05

Peak powers, fortissimo playing. Orchestra of 75 pieces. Both peak and average powers of orchestra are about 10,000 times such for conversational speech. Violin played as softly as possible, 4 microwatts. Threefold peak power 20,000,000 times this.

TABLE 150.—Relative Strength of the Partials in Various Musical Instruments

The values given are for tones of medium loudness. Individual tones vary greatly in quality and, therefore, in loudness.

Instrument.	Strength of partials in per cent of total tone strength.											
	1	2	3	4	5	6	7	8	9	10	11	12
Tuning fork on box..	100	—	—	—	—	—	—	—	—	—	—	—
Flute.............	66	24	4	6	—	—	—	—	—	—	—	—
Violin, A string.....	26	25	9	10	27	1	0	2	—	—	—	—
Oboe.............	2	2	4	29	35	14	4	2	3	4	1	0
Clarinet..........	12	0	10	3	5	0	8	18	15	18	5	6
Horn.............	36	26	17	7	4	3	2	1	1	1	1	1
Trombone..........	6	11	35	12	8	11	6	4	3	2	1	1

TABLE 151.—Miscellaneous Sound Data

Koenig's temperature coefficient for the frequency (n) of forks is nearly the same for all pitches. $n_t = n_0(1 - 0.00011t° \text{ C})$, Ann. d. Phys. 9, p. 408, 1880.

Vibration frequencies for continuous sound sensations are practically the same as for continuous light sensation, 10 or more per second. Helmholtz' value of 32 per sec. may be taken as the flicker value for the ear. Moving pictures use 16 or more per sec. For light the number varies with the intensity.

The quality of a musical tone depends solely on the number and relative strength of its partials (simple tones) and probably not at all on their phases.

The wave lengths of sound issuing from a closed pipe of length L are $4L$, $4L/3$, $4L/5$, etc., and from an open pipe, $2L$, $2L/2$, $2L/3$, etc. The end correction for a pipe with a flange is such that the antinode is 0.82 × radius of pipe beyond the end; with no flange the correction is 0.57 × radius of pipe.

The energy of a pure sine wave is proportional to n^2A^2; the energy per cm³ is on the average $2\rho\pi^2U^2A^2/\lambda^2$; the energy passing per sec. through 1 cm² perpendicular to direction of propagation is $2\rho\pi^2U^3A^2/\lambda^2$; the pressure is $\frac{1}{2}(\gamma + 1)$ (average energy per cm³); where n is the vibration number per sec., λ the wave length, A the amplitude, V the velocity of sound, ρ the density of the medium, γ the specific heat ratio. Altberg (Ann. d. Phys. 11, p. 405, 1903) measured sound-wave pressures of the order of 0.24 dynes/cm² = 0.00018 mm Hg.

TABLE 152.—Audibility as Dependent on Sound Pressure and Frequency

The ear detects sounds over a pressure range about 0.001 to 1000 dynes/cm²; over much of this range it differentiates between complex sounds so nearly alike that no existing physical device can distinguish them. Plot shows minimum audibility pressures from 72 normal ears from 60 to 4000 cycles (both scales logarithmic); standard deviation indicated by dotted curves. The maximum audibility curve was obtained from 48 normal ears. A louder sound becomes painful. The intensity of pressure necessary is about that required to excite the tactile nerves in the finger tips. (Wegel, Pr. Nat. Acad. Sc., 8, p. 155, 1922.)

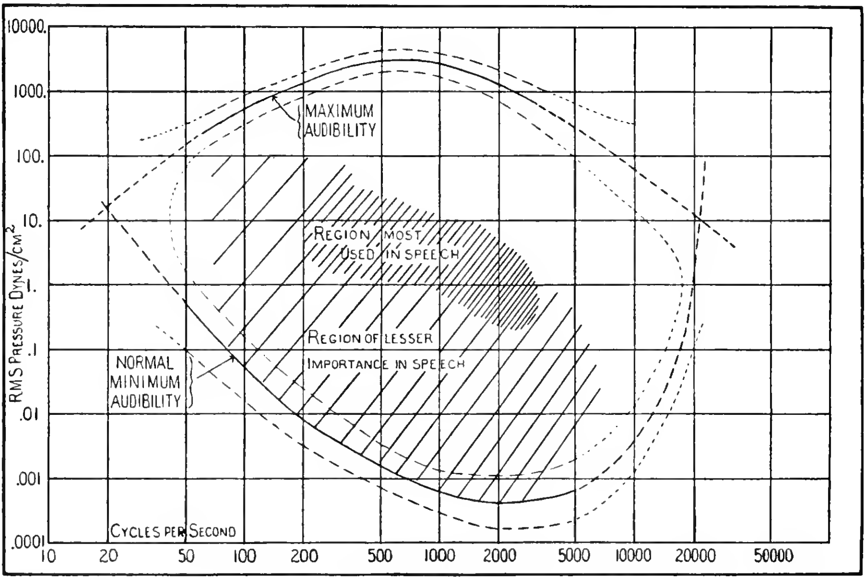


TABLE 153.—Speech

(Fletcher, Rev. Mod. Phys., 3, 258, 1931.)

Speech is composed of vowels and consonants. Most are continued in steady tones (continuants), long vowels, a, short, i, diphthongs, ou, semivowels, l, fricative consonants, s; others are interrupted (stops). The pure stops are p, t, ch, k; voiced, b, d, j, g.

When frequencies, f, are measured in kilocycles, then the pitch $P = \log_2 F$. J is the intensity of the sound passing through a cm^2 of the wave-front. The intensity level $I = \log_{10} J$ and is expressed in bells.

TABLE 154.—Characteristic Resonance Values for Spoken Vowels

The larynx generates a fundamental tone of a *chosen* pitch with some 20 partials, usually of low intensity. The particular partial, or partials, most nearly in unison with the mouth cavity is greatly strengthened by resonance. Each vowel, for a given mouth, is characterized by a particular *fixed* pitch, or pitches, of resonance corresponding to that vowel's definite form of mouth cavity. These pitches may be judged by whispering the vowels. It is difficult to sing vowels true above the corresponding pitches. The greater part of the energy or loudness of a vowel of a *chosen* pitch is in those partials reinforced by resonance. The vowels may be divided into two classes,— the first having one characteristic resonance region, the second, two. The representative pitches of maximum resonance of a mouth cavity for selected vowels in each group are given in the following table.

Vowel indicated by italics in the words.	Pitch of maximum resonance.	Vowel indicated by italics in the words.	Pitch of maximum resonance.
f*a*ther, f*a*r, gu*a*rd	910	m*a*t, *a*dd, c*a*t	800 and 1840
r*aw*, f*a*ll, h*au*l	732	p*e*t, f*ea*ther, bl*e*ss	691 and 1953
n*o*, r*o*de, g*oa*l	461	th*ey*, b*ai*t, h*a*te	488 and 2461
gl*oo*m, m*o*ve, gr*ou*p	326	b*ee*, p*i*que, mach*i*ne	308 and 3100

Pitch in octaves from one kilocycle. For the first 6 vowels high pitch region less intense (Fletcher).

pool	− 0.3 − 1.3	talk	− 0.1 − 0.7	tap	− 0.45 + 0.8	tip	− 1.2 + 1.2
put	0.0 − 1.1	ton	+ 0.2 − 0.5	ten	− 0.7 + 0.9	team	− 1.4 + 1.3
tone	− 0.2 − 1.0	father	+ 0.3 − 0.3	tape	− 0.9 + 1.1		

TABLE 155.—Speech Power (Fletcher)

Average conversational speech power, 10 microwatts or 100 ergs per second. About 1/3 of time no sound is flowing (pauses), so if silent intervals are excluded these values may be taken as 15 and 150. Shouting as loud as possible increases 100-fold, whispering intelligibly 1/10,000. The *mean speech power* may be defined as average over 1/100 sec. period; *phonetic speech power*, max. value of mean speech power of a fundamental vowel or consonant; *peak speech power*, max. value of instantaneous power over interval considered.

TABLE 156.—Phonetic Powers, Average Conversation

ó	680	ō	470	ū	310	l	100	ch	42	s	16	v	12	f	5
a	600	u	460	i	260	sh	80	n	36	t	15	b	7	th	1
o	510	ā	370	ē	220	ng	73	j	23	g	15	d	7		
á	490	e	350	r	210	m	52	z	16	k	13	p	6		

The most powerful sound is "*awl*,"—900 times the power of *th* in *thigh*. Intoned without emphasis it is about 50 microvolts. Peak powers are 10-20 times the phonetic power. In ordinary conversation 2% of time > 20 db over average level; 42%, 6 to 16 db.

NOTE.—For Bibliography of Acoustics of Buildings (Watson) see Nat. Res. Council, Reprint, and Circulars, No. 98, 1931, or Journ. Acoust. Soc. Amer., 2, 14, 1931.

TABLE 157

VELOCITY PRESSURE AT DIFFERENT AIR SPEEDS

The resistance F of a body of fixed shape and presentation moving through a fluid may be written

$$F = \rho L^2 V^2 \left(\frac{VL\rho}{\mu} \right) \qquad (1)$$

in which ρ denotes the fluid density, μ the viscosity, L a linear dimension of the body fixing the scale, and V is the speed of the body relative to the fluid. The dimensionless ratio $\frac{VL\rho}{\mu}$ is termed the Reynolds Number R. Values of R are comparable only for geometrically similar bodies. The quantity $(1/2)\rho V^2$ is termed the velocity pressure q; it is the increase in pressure above the static pressure set up in a tube whose open end is pointed into the relative wind. The relation (1) is usually written $F = CAq$, A being some specifically defined area as, for example, the area of the projection of the body on a plane normal to the wind. C is usually termed the absolute resistance coefficient. It has the same value in any self-consistent system of units and is a function of the Reynolds Number R. The method of defining A and L must in every case be explicitly stated.

For speeds near the speed of sound, C is also a function of the ratio of the air speed to the speed of sound. Values given in these Tables can not then be used.

The table gives values of the velocity pressure q at different air speeds. In conjunction with the values of C in subsequent tables, this table can be used for computation of the resistance under specified conditions. It is computed for standard air density: dry air, normal CO_2 content, 15°C, one atmosphere, standard gravity,

$$0.12497 \frac{\text{metric slugs}}{\text{m}^3} \left(\frac{\text{Kg(mass)}}{9.807 \text{ m}^3} \right) = 0.002378 \frac{\text{slugs}}{\text{ft.}^3} \left(\frac{\text{lbs. (mass)}}{32.156 \text{ ft.}^3} \right)$$

For other densities the values must be multiplied by the ratio of the actual density to the standard density.

Air speed m/sec.	Pressure, q kg/m²	Air speed m/sec.	Pressure, q kg/m²	Air speed m/sec.	Pressure, q kg/m²	Air speed m/sec.	Pressure, q kg/m²	Air speed m/sec.	Pressure, q kg/m²
1	0.063	11	7.56	21	27.56	31	60.06	41	105.1
2	.250	12	9.00	22	30.25	32	64.00	42	110.3
3	.562	13	10.56	23	33.06	33	68.06	43	115.6
4	1.00	14	12.25	24	36.00	34	72.25	44	121.0
5	1.56	15	14.06	25	39.06	35	76.56	45	126.6
6	2.25	16	16.00	26	42.25	36	81.00	46	132.2
7	3.06	17	18.06	27	45.56	37	85.56	47	138.1
8	4.00	18	20.25	28	49.00	38	90.25	48	144.0
9	5.06	19	22.56	29	52.56	39	95.06	49	150.1
10	6.25	20	25.00	30	56.25	40	100.0	50	156.3
Air speed ft./sec.	Pressure, q lb./ft.²	Air speed ft./sec.	Pressure, q lb./ft.²	Air speed ft./sec.	Pressure, q lb./ft.²	Air speed ft./sec.	Pressure, q lb./ft.²	Air speed ft./sec.	Pressure, q lb./ft.²
1	0.00119	11	.1438	21	.5243	55	3.597	105	13.11
2	.00476	12	.1712	22	.5755	60	4.280	110	14.39
3	.01070	13	.2009	23	.6290	65	5.024	115	15.72
4	.0190	14	.2330	24	.6849	70	5.826	120	17.12
5	.0297	15	.2675	25	.7431	75	6.688	125	18.58
6	.0428	16	.3044	30	1.070	80	7.610	130	20.09
7	.0583	17	.3436	35	1.457	85	8.591	135	21.67
8	.0761	18	.3852	40	1.902	90	9.631	140	23.30
9	.0963	19	.4292	45	2.408	95	10.73	145	25.00
10	.1189	20	.4756	50	2.973	100	11.89	150	26.75

TABLE 158

CORRECTIONS TO ROBINSON CUP ANEMOMETERS

The official Weather Bureau instrument used for measuring speed of natural winds is a Robinson type cup anemometer. Before January 1, 1928, a four-cup driving unit was used; after that date a three-cup unit, because of the large errors of the older type at high speeds. The table gives the speeds indicated by the old and new instruments at various true speeds.

True speed, miles per hour	Indicated speed, four-cup standard, miles per hour	Indicated speed, three-cup standard, miles per hour	True speed, miles per hour	Indicated speed, four-cup standard, miles per hour	Indicated speed, three-cup standard, miles per hour	True speed, miles per hour	Indicated speed, four-cup standard, miles per hour	Indicated speed, three-cup standard, miles per hour
5	5	5	40	50	41	75	98	79
10	11	10	45	57	47	80	105	84
15	17	15	50	64	52	85	112	89
20	23	20	55	71	57	90	118	95
25	30	25	60	78	63	95	125	100
30	37	31	65	85	68	100	132	105
35	44	36	70	91	73	110	145	116

NOTE.—Values above a true speed of 75 miles per hour are extrapolated.

It must be borne in mind that problems in aerodynamics can not be idealized as easily as many problems in mechanics. The side of a building may not be regarded as a thin flat plate in computing the force of the wind, and data for a cylinder of a given length can not be directly applied for the wind force on a cylinder of some other length. Further, objects nearby exert an appreciable influence.

These complications limit the strict application of a test on a particular object to geometrically similar objects in similar surroundings. They also cause apparent discrepancies among the results of different experimenters which are to be attributed to departure from geometrical similarity of the models, to the effects of the relative size of the body and the air stream, of the supports or other nearby objects, and to differences in the fine structure (turbulence) of the approximately steady air streams rather than to errors of measuring.

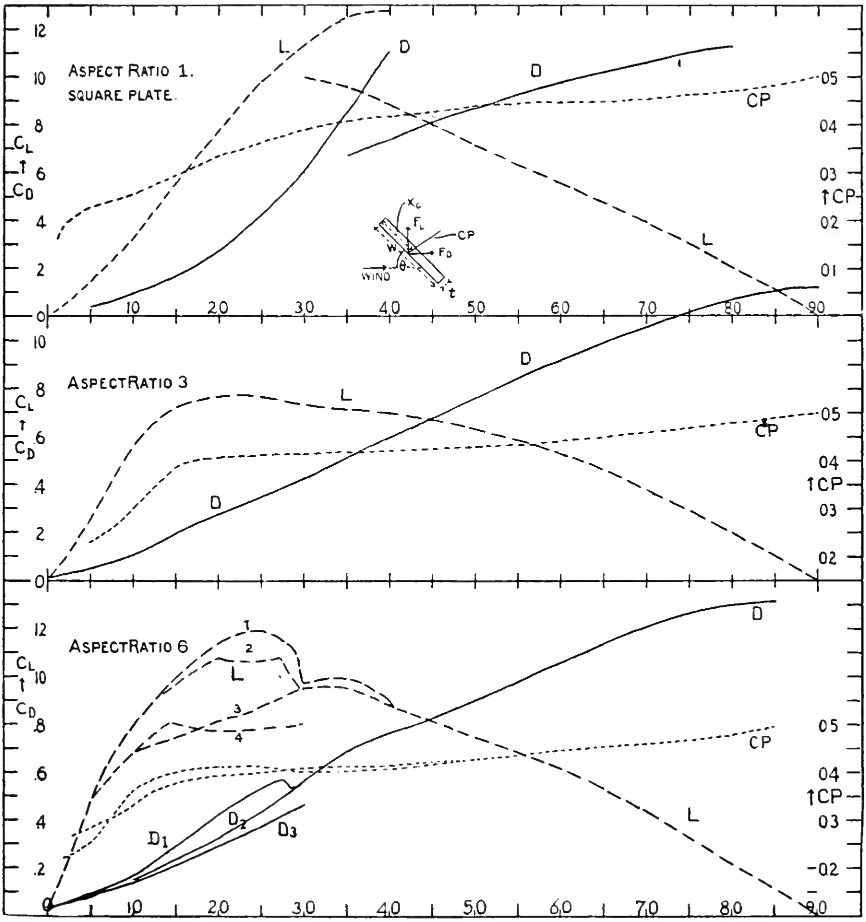
The data here given are intended to apply to the ideal condition of an isolated body of exactly the shape specified in a uniform, steady air stream of infinite extent.

Example of tables: Take the problem of the resistance of a sphere 1.5 cm. diam. moving at a speed 35 m/sec. (3500 cm/sec.) through still air of density 0.0010 g/cm^3 and viscosity 0.000173 g/cm sec. The Reynolds number is $3500 \times 1.5 \times 0.0010/0.000173$ or 30,347; $\log_{10} R$ is 4.482; whence from Table 162 C is 0.50. From Table 157 the value of q for std. density is 76.56 kg(force)/m^2. The ratio of the actual to std. density is 0.0010/0.0012255 or 0.816. The resistance is therefore $\{0.50\}\{\pi/4\}\{1.5/100\}^2\{76.56\}\{0.816\} = 0.00552$ kg(force) = 5413 dynes.

RESISTANCE COEFFICIENT FOR THIN FLAT PLATES NORMAL TO THE WIND

The pressure on a thin rectangular plate varies with the "aspect ratio," a term introduced by Langley for the ratio of the length of the leading edge (span) to the chord length. The resistance coefficient is nearly independent of the Reynolds Number if the Reynolds Number (L taken as the chord length) is greater than 100. In the following table the values of C are given as a function of the aspect ratio. A is taken as the area of the plane, viz., product of chord and span. Values of C for circular disks are practically the same as for a square plate.

Aspect ratio	1	2	3	4	5	6	7	8	∞
C	1.12	1.18	1.22	1.24	1.26	1.28	1.30	1.32	2.00



COEFFICIENTS OF RECTANGULAR PLATES, SEE P. 199.

FORCES ON THIN FLAT PLATES AT ANGLES TO THE WIND

For plates at angles, the force is usually resolved into components at right angles and parallel to the direction of the relative wind. The components, termed the lift and drag respectively, are expressed in the form of absolute coefficients, the forces being divided by the product of the velocity pressure and the area of the plate (N. B.—*not* the projected area on a plane normal to the wind). The line of action of the force is given by the intersection of the resultant force with the plate expressed as the ratio of the distance of the intersection from the leading edge to the chord length, a quantity called the center of pressure coefficient. The lift coefficient L = lift/Aq, the drag coefficient D = drag/Aq, and the center of pressure coefficient for various angles are given for plates of aspect ratios 1, 3, and 6 in the form of graphs. (See page 198.)

The following formulae indicate the use of the coefficients from the plots for the determination of the forces:

F_d = component of resulting wind force parallel to wind = drag = DAq;
F_l = that normal to wind and width = lift = LAq;
x_c (see small figure in upper set of curves) = $\overline{CP} \cdot W$; W is that dimension of the plane of reference which makes the least angle with wind.
A = area of one surface of plate. D, L, $\overline{CP}$ are independent of Reynold's No. and temperature.

Authorities and the conditions of their experiments: (1) Eiffel. (2) Dines, 1890. (3) Föppl, 1910. (4) Riabouchinski, 1912. (5) Stanton, 1903. (6) Bureau of Standards. In lower figure of previous page: L_1, Föppl; L_2, L_3, B. of S.; L_4, Eiffel; D_1, Föppl, B. of S.; D_2, B. of S.; D_3, Eiffel. For more detailed information as to references and data see I.C.T. 1, 406, 1926.

Authority	Aspect ratio 1				Aspect ratio 3			Aspect ratio 6			
	(1)	(2)	(3)	(4)	(1)	(3)	(5)	(1)	(3)	(6)	(6)
Span	25	30.5	12	12	45	7.6	36	90	30.5	72	30.5
Chord	25	30.5	12	12	15	2.5	12	15	5.08	12	5.08
Thickness	.33	.32	.17		.3	.025	.17	.3	.117	.17	.129
Tunnel diam.	1500	∞	2000	1200	1500	600	2000	1500	1370	2000	1370
Reynold's No.	210	382	55	42	126	10	55	126	64	55	64

TABLE 161

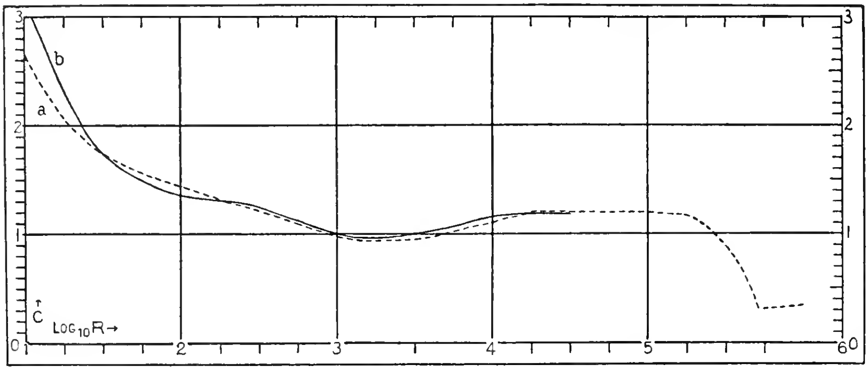
FORCES ON NON-ROTATING CIRCULAR CYLINDERS

The coefficient for cylinders normal to the wind, the area A being taken as the product of length and diameter and the linear dimension L as the diameter, depends to a marked degree on the ratio of length to diameter and on the Reynolds Number, R. The graph shows the variation of C with R for cylinders of infinite length.

The variation of C with the length-diameter ratio for a Reynolds Number of 80,000 is as follows:

Ratio of length to diameter	1	2	3	5	10	20	40	
C	0.63	.69	.75	.74	.83	.92	1.00	1.20

If the axis of the cylinder is inclined to the wind direction, the force remains approximately at right angles to the axis of the cylinder, its magnitude falling off approximately as the square of the sine of the angle of the axis to the wind.



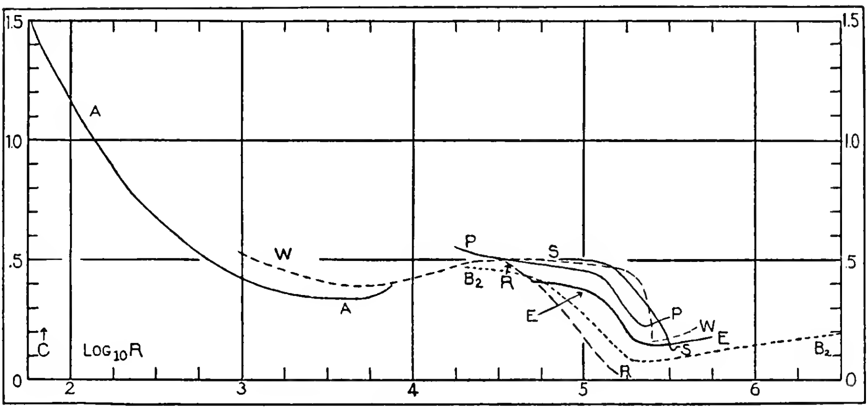
AIR FORCES, CIRCULAR CYLINDERS.

Force $= CAq$. Reynold's number $= R = VD\rho/\mu$.

C is taken from above plot; for q see Table 157; $A =$ Area axial section of cylinder $=$ L (length) $\times D$ (diameter); the plane of reference contains the axis and is perpendicular to the plane defined by the axis and the wind direction; $V =$ air speed; ρ, the density of the medium and μ, its viscosity. Curve (a) is due to Wieselsberger, 1922; curve (b) to Relf.

TABLE 162.—Forces on Spheres

For spheres the linear dimension L is taken as the diameter of the sphere D and the area as $\frac{\pi D^2}{4}$. For values of the Reynolds Number between 80,000 and 300,000 the value of C depends in large measure on the turbulence of the air stream (*cf.* Technical Report 342 of the National Advisory Committee for Aeronautics). The curves marked S and W most clearly approximate the condition of zero turbulence.



AIR FORCES ON SPHERES.

$$\text{Force} = F = CAq. \quad A = \pi D^2/4. \quad R = VD\rho/\mu.$$

For meaning of letters see previous table.

Authorities: A, Allen, 1900; B_2, Bacon and Reid; E, Eiffel; P, Pannell; R, Riabouchinski, 1914; S, Bureau of Standards; W, Wieselsberger, 1914, 1922. For more detailed references see I.C.T., 1, 411, 1926.

TABLE 163.—Forces on Miscellaneous Bodies

The values of the shape coefficients in the following table are to be used with the area of the projection of the body on a plane normal to the wind direction. Where this projection is a circle, the diameter is used as the quantity L in the Reynolds Number. Where the projection is rectangular, the shortest side of the rectangle is taken as L.

TABLE 163 (continued).—Forces on Miscellaneous Bodies

Body	C	Reynolds Number
Struts (bodies streamlined in two dimensions)	0.06–0.08	above 40,000
Streamline bodies of revolution	0.03–0.04	above 100,000
Rectangular prism, 1 x 1 x 3, normal to 1 x 3 face	1.60 *	400,000
Model of automobile	.78 *	about 300,000
Cone, angle 60°, diam. base 40 cm, point to wind, solid	.51	about 270,000
Cone, angle 30°, diam. base 40 cm, point to wind, solid	.34	270,000
Hemisphere, convex to wind	.34	170,000
Hemisphere, concave to wind	.13	170,000
Concave cup	1.39	170,000
Convex cup	.35	170,000
Sphero-conic body, diam. 20 cm, cone 20° point forward	.16	135,000
Sphero-conic body, diam. 20 cm, cone 20° point to rear	.088	135,000
Cylinder 120 cm long, spherical ends	.19	100,000

* C varies very little with Reynolds Number.

TABLE 164.—Forces on Cylinders

Cylinder, base perpendicular to wind, $\frac{\text{length}}{\text{diameter}}$		C *	
	0	1.07	100,000 to 200,000
"	1	1.07	"
"	2	.88	"
"	4	.81	"
"	6	.82	"
"	8	.82	"
"	14	.94	"

* Eiffel's values: See Table 159 for best value, 1.12.

SKIN FRICTION

The surface friction on well-varnished surfaces of thin flat plates may be expressed in the following form:

$$R_F = 0.0375AqR^{-0.15}$$

where R_F is the frictional force on the area A exposed to the stream, q is the velocity pressure, and R the Reynolds Number based on the length of the plate parallel to the wind direction. The values in the table apply when the flow is fully turbulent as in most practical applications. (*Cf.* Technical Report 342 of the National Advisory Committee for Aeronautics.)

Speed m/sec.	Skin friction kg per sq. m plane: 1 m long	Skin friction kg per sq. m plane: 30 m long	Speed ft./sec.	Skin friction lbs. per sq. ft. plane: 1 ft. long	Skin friction lbs. per sq. ft. plane: 30 ft. long
10	0.0311	0.0187	10	0.00083	0.00050
20	.112	.0673	20	.00303	.00182
30	.237	.142	30	.00641	.00385
40	.404	.243	40	.0109	.00655
50	.611	.366	50	.0164	.00987
60	.856	.514	60	.0231	.0139
70	1.138	.683	70	.0307	.0184
80	1.457	.874	80	.0393	.0236
90	1.812	1.087	90	.0488	.0293
100	2.202	1.321	100	.0594	.0356
110	2.626	1.576	110	.0708	.0425
120	3.085	1.851	120	.0831	.0499
130	3.577	2.146	130	.0964	.0579
140	4.102	2.461	140	.1106	.0664
150	4.662	2.797	150	.1256	.0754
160	5.253	3.152	160	.1416	.0850
170	5.875	3.525	170	.1584	.0951
180	6.531	3.919	180	.1761	.1057
190	7.218	4.331	190	.1946	.1168
200	7.937	4.762	200	.2140	.1284

TABLE 166.—Friction

The required force F necessary to just move an object along a horizontal plane $= fN$ where N is the normal pressure on the plane and f the "coefficient of friction." The angle of repose Φ ($\tan \Phi = F/N$) is the angle at which the plane must be tilted before the object will move from its own weight. The following table of coefficients was compiled by Rankine from the results of General Morin and other authorities and is sufficient for ordinary purposes.

Material.	f	$1/f$	ϕ
Wood on wood, dry	.25–.50	4.00–2.00	14.0–26.5
" " " soapy	.20	5.00	11.5
Metals on oak, dry	.50–.60	2.00–1.67	26.5–31.0
" " " wet	.24–.26	4.17–3.85	13.5–14.5
" " " soapy	.20	5.00	11.5
" " elm, dry	.20–.25	5.00–4.00	11.5–14.0
Hemp on oak, dry	.53	1.89	28.0
" " " wet	.33	3.00	18.5
Leather on oak	.27–.38	3.70–2.86	15.0–19.5
" " metals, dry	.56	1.79	29.5
" " " wet	.36	2.78	20.0
" " " greasy	.23	4.35	13.0
" " " oily	.15	6.67	8.5
Metals on metals, dry	.15–.20	6.67–5.00	8.5–11.5
" " " wet	.3	3.33	16.5
Smooth surfaces, occasionally greased	.07–.08	14.3–12.50	4.0–4.5
" " continually greased	.05	20.00	3.0
" " best results	.03–.036	33.3–27.6	1.75–2.0
Steel on agate, dry *	.20	5.00	11.5
" " " oiled *	.107	9.35	6.1
Iron on stone	.30–.70	3.33–1.43	16.7–35.0
Wood on stone	About .40	2.50	22.0
Masonry and brick work, dry	.60–.70	1.67–1.43	33.0–35.0
" " " " damp mortar	.74	1.35	36.5
" on dry clay	.51	1.96	27.0
" " moist clay	.33	3.00	18.25
Earth on earth	.25–1.00	4.00–1.00	14.0–45.0
" " " dry sand, clay, and mixed earth	.38–.75	2.63–1.33	21.0–37.0
" " " damp clay	1.00	1.00	45.0
" " " wet clay	.31	3.23	17.0
" " " shingle and gravel	.81–1.11	1.23–0.9	39.0–48.0

* Quoted from a paper by Jenkin and Ewing, "Phil. Trans. R. S." vol. 167. In this paper it is shown that in cases where "static friction" exceeds "kinetic friction" there is a gradual increase of the coefficient of friction as the speed is reduced towards zero.

TABLE 167.—Lubricants

The best lubricants are in general the following: Low temperatures, light mineral lubricating oils. Very great pressures, slow speeds, graphite, soapstone and other solid lubricants. Heavy pressures, slow speeds, ditto and lard, tallow and other greases. Heavy pressures and high speeds, sperm oil, castor oil, heavy mineral oils. Light pressures, high speeds, sperm, refined petroleum olive, rape, cottonseed. Ordinary machinery, lard oil, tallow oil, heavy mineral oils and the heavier vegetable oils. Steam cylinders, heavy mineral oils, lard, tallow. Watches and delicate mechanisms, clarified sperm, neat's-foot, porpoise, olive and light mineral lubricating oils.

TABLE 168.—Lubricants For Cutting Tools

Material.	Turning.	Chucking.	Drilling.	Tapping Milling.	Reaming.
Tool Steel,	dry or oil	oil or s. w.	oil	oil	lard oil
Soft Steel,	dry or soda water	soda water	oil or s. w.	oil	lard oil
Wrought iron	dry or soda water	soda water	oil or s. w.	oil	lard oil
Cast iron, brass	dry	dry	dry	dry	dry
Copper	dry	dry	dry	dry	mixture
Glass	turpentine or kerosene				

Mixture = $\frac{1}{3}$ crude petroleum, $\frac{2}{3}$ lard oil. Oil = sperm or lard.

Tables 167 and 168 quoted from "Friction and Lost Work in Machinery and Mill Work," Thurston, Wiley and Sons.

TABLE 169.—Viscosity of Fluids and Solids

The coefficient of viscosity of a substance is the tangential force required to move a unit area of a plane surface with unit speed relative to another parallel plane surface from which it is separated by a layer a unit thick of the substance. Viscosity measures the temporary rigidity it gives to the substance. The viscosity of fluids is generally measured by the rate of flow of the fluid through a capillary tube the length of which is great in comparison with its diameter. The equation generally used is

$$\mu, \text{ the viscosity}, = \frac{\gamma \pi g d^4 t}{128 Q(l+\lambda)} \left(h - \frac{mv^2}{g}\right),$$

where γ is the density (g/cm^3), d and l are the diameter and length in cm of the tube, Q the volume in cm^3 discharged in t sec., λ the Couette correction which corrects the measured to the effective length of the tube, h the average head in cm, m the coefficient of kinetic energy correction, mv^2/g, necessary for the loss of energy due to turbulent in distinction from viscous flow, g being the acceleration of gravity (cm/sec/sec), v the mean velocity in cm per sec. (See Technologic Paper of the Bureau of Standards, 100 and 112, Herschel, 1917–1918, for discussion of this correction and λ.)

The fluidity is the reciprocal of the absolute viscosity. The kinetic viscosity is the absolute viscosity divided by the density. Specific viscosity is the viscosity relative to that of some standard substance, generally water, at some definite temperature. The dimensions of viscosity are $ML^{-1}T^{-1}$. It is generally expressed in cgs units as dyne-seconds per cm^2 or poises.

The viscosity of solids may be measured in relative terms by the damping of the oscillations of suspended wires (see Table 82). Ladenburg (1906) gives the viscosity of Venice turpentine at 18.3° as 1300 poises; Trouton and Andrews (1904) of pitch at 0°, 51×10^{10}, at 15°, 1.3×10^{10}; of shoemakers' wax at 8°, 4.7×10^6; of soda glass at 575°, 11×10^{12}; Deeley (1908) of glacier ice as 12×10^{13}.

TABLE 170.—Viscosity of Water in Centipoises (Temperature Variation)

Bingham and Jackson, Bulletin Bureau of Standards, 14, 75, 1917. Pressure effect, see p. 652.

° C.	Viscosity. cp	° C.	Viscosity. cp	° C.	Viscosity. cp	° C.	Viscosity. cp	° C.	Viscosity. cp	° C.	Viscosity. cp	° C.	Viscosity. cp
0	1.7921	10	1.3077	20	1.0050	30	0.8007	40	0.6560	50	0.5494	60	0.4688
1	1.7313	11	1.2713	21	0.9810	31	0.7840	41	0.6439	51	0.5404	65	0.4355
2	1.6728	12	1.2363	22	0.9579	32	0.7679	42	0.6321	52	0.5315	70	0.4061
3	1.6191	13	1.2028	23	0.9358	33	0.7523	43	0.6207	53	0.5229	75	0.3799
4	1.5674	14	1.1709	24	0.9142	34	0.7371	44	0.6097	54	0.5146	80	0.3565
5	1.5188	15	1.1404	25	0.8937	35	0.7225	45	0.5988	55	0.5064	85	0.3355
6	1.4728	16	1.1111	26	0.8737	36	0.7085	46	0.5883	56	0.4985	90	0.3165
7	1.4284	17	1.0828	27	0.8545	37	0.6947	47	0.5782	57	0.4907	95	0.2994
8	1.3860	18	1.0559	28	0.8360	38	0.6814	48	0.5683	58	0.4832	100	0.2838
9	1.3462	19	1.0299	29	0.8180	39	0.6685	49	0.5588	59	0.4759	153	0.181 *

* de Haas, 1894. Undercooled water: −2.10°, 1.33 cp; −4.70°, 2.12 cp; −6.20°, 2.25 cp; −8.48°, 2.46 cp; −9.30°, 2.55 cp; White, Twining, J. Amer. Ch. Soc., 50, 380, 1913.

TABLE 171.—Viscosity of Alcohol-water Mixtures in Centipoises (Temperature Variation)

° C.	Percentage by weight of ethyl alcohol.												
	0	10	20	30	39	40	45	50	60	70	80	90	100
0	1.792	3.311	5.319	6.94	7.25	7.14	6.94	6.58	5.75	4.762	3.690	2.732	1.773
5	1.519	2.577	4.065	5.29	5.62	5.59	5.50	5.26	4.63	3.906	3.125	2.309	1 623
10	1.308	2.179	3.165	4.05	4.39	4.39	4.35	4.18	3.77	3.268	2.710	2.101	1.460
15	1.140	1.792	2.618	3.26	3.52	3.53	3.51	3.44	3.14	2.770	2.309	1.802	1.332
20	1.005	1.538	2.183	2.71	2.88	2.91	2.88	2.87	2.67	2.370	2.008	1.610	1.200
25	0.894	1.323	1.815	2.18	2.35	2.35	2.39	2.40	2.24	2.037	1.748	1.424	1.096
30	0.801	1.160	1.553	1.87	2.00	2.02	2.02	2.02	1.93	1.767	1.531	1.279	1.003
35	0.722	1.006	1.332	1.58	1.71	1.72	1.73	1.72	1.66	1.529	1.355	1.147	0.914
40	0.656	0.907	1.160	1.368	1.473	1.482	1.495	1.499	1.447	1.344	1.203	1.035	0.834
45	0.599	0.812	1.015	1.189	1.284	1.289	1.307	1.294	1.271	1.189	1.081	0.939	0.764
50	0.549	0.734	0.907	1.050	1.124	1.132	1.148	1.155	1.127	1.062	0.968	0.848	0.702
60	0.469	0.609	0.736	0.834	0.885	0.893	0.907	0.913	0.902	0.856	0.789	0.704	0.592
70	0.406	0.514	0.608	0.683	0.725	0.727	0.740	0.740	0.729	0.695	0.650	0.589	0.504
80	0.356	0.430	0.505	0.567	0.598	0.601	0.609	0.612	0.604	—	—	—	—

Same authority as preceding table.

TABLE 172.—Viscosity and Density of Sucrose in Aqueous Solution

See Scientific Paper 298, Bingham and Jackson, Bureau of Standards, 1917, and Technologic Paper 100, Herschel, Bureau of Standards, 1917.

Temperature.	Viscosity in centipoises. Per cent sucrose by weight.				Density d_4^t. Per cent sucrose by weight.			
	0	20	40	60	0	20	40	60
0° C	1.7921	3.804	14.77	238.	0.99987	1.08546	1.18349	1.29560
5	1.5188	3.154	11.56	156.	0.99999	1.08460	1.18192	1.29341
10	1.3077	2.652	9.794	109.8	0.99973	1.08353	1.18020	1.29117
15	1.1404	2.267	7.468	74.6	0.99913	1.08233	1.17837	1.28884
20	1.0050	1.960	6.200	56.5	0.99823	1.08094	1.17648	1.28644
30	0.8007	1.504	4.382	33.78	0.99568	1.07767	1.17214	1.28144
40	0.6560	1.193	3.249	21.28	0.99225	1.07366	1.16759	1.27615
50	0.5494	0.970	2.497	14.01	0.98807	1.06898	1.16248	1.27058
60	0.4688	0.808	1.982	9.83	0.98330	1.06358	1.15693	1.26468
70	0.4061	0.685	1.608	7.15				
80	0.3565	0.590	1.334	5.40	Densities due to Plato.			

TABLE 173.—Viscosity and Density of Glycerol in Aqueous Solution (20° C)

% Glycerol.	Density. g/cm³	Viscosity in centipoises.	100 × Kinematic viscosity.	% Glycerol.	Density. g/cm³	Viscosity in centipoises.	100 × Kinematic viscosity.	% Glycerol.	Density. g/cm³	Viscosity in centipoises.	100 × Kinematic viscosity.
5	1.0098	1.181	1.170	35	1.0855	3.115	2.870	65	1.1662	14.51	12.44
10	1.0217	1.364	1.335	40	1.0989	3.791	3.450	70	1.1797	21.49	18.22
15	1.0337	1.580	1.529	45	1.1124	4.692	4.218	75	1.1932	33.71	28.25
20	1.0461	1.846	1.765	50	1.1258	5.908	5.248	80	1.2066	55.34	45.86
25	1.0590	2.176	2.055	55	1.1393	7.664	6.727	85	1.2201	102.5	84.01
30	1.0720	2.585	2.411	60	1.1528	10.31	8.943	90	1.2335	207.6	168.3

The kinematic viscosity is the ordinary viscosity in cgs units (poises) divided by the density.

TABLE 174.—Viscosity and Density of Castor Oil (Temperature Variation)

° C	Density, g/cm³	Viscosity in poises.	Kinematic viscosity.	° C	Density, g/cm³	Viscosity in poises.	Kinematic viscosity.	° C	Density, g/cm³	Viscosity in poises.	Kinematic viscosity.	° C	Density, g/cm³	Viscosity in poises.	Kinematic viscosity.
5	.9707	37.6	38.7	14	.9645	16.61	17.22	23	.9583	7.67	8.00	32	.9520	3.94	4.14
6	.9700	34.5	35.5	15	.9638	15.14	15.71	24	.9576	7.06	7.37	33	.9513	3.65	3.84
7	.9693	31.6	32.6	16	.9631	13.80	14.33	25	.9569	6.51	6.80	34	.9506	3.40	3.58
8	.9686	28.9	29.8	17	.9624	12.65	13.14	26	.9562	6.04	6.32	35	.9499	3.16	3.33
9	.9679	26.4	27.3	18	.9617	11.62	12.09	27	.9555	5.61	5.87	36	.9492	2.94	3.10
10	.9672	24.2	25.0	19	.9610	10.71	11.15	28	.9548	5.21	5.46	37	.9485	2.74	2.89
11	.9665	22.1	22.8	20	.9603	9.86	10.27	29	.9541	4.85	5.08	38	.9478	2.58	2.72
12	.9659	20.1	20.8	21	.9596	9.06	9.44	30	.9534	4.51	4.73	39	.9471	2.44	2.58
13	.9652	18.2	18.9	22	.9589	8.34	8.70	31	.9527	4.21	4.42	40	.9464	2.31	2.44

Tables 173 and 174, taken from Technologic Paper 112, Bureau of Standards, 1918. Glycerol data due to Archbutt, Deeley and Gerlach; Castor Oil to Kahlbaum and Räber. See preceding table for definition of kinematic viscosity. Archbutt and Deeley give for the density and viscosity of castor oil at 65.6° C, 0.9284 and 0.605, respectively; at 100° C, 0.9050 and 0.169.

TABLE 175.—Viscosity of Organic Liquids

Compiled from Landolt and Börnstein, 1912. Based principally on work of Thorpe and Rogers, 1894–97. Viscosity given in centipoises. One centipoise = 0.01 dyne-second per cm².

Liquid	Viscosity in centipoises								
	Formula	0°C	10°C	20°C	30°C	40°C	50°C	70°C	100°C
Acids: Formic	CH_2O_2	solid	2.247	1.784	1.460	1.219	1.036	.780	.549
Acetic	$C_2H_4O_2$	solid	solid	1.222	1.040	.905	.796	.631	.465
Propionic	$C_3H_6O_2$	1.521	1.289	1.102	.960	.845	.752	.607	.459
Butyric	$C_4H_8O_2$	2.286	1.851	1.540	1.304	1.120	.975	.760	.551
Alcohols: Methyl	CH_4O	.817	.690	.596	.520	.456	.403	....	....
Allyl	C_3H_6O	2.145	1.705	1.363	1.168	.914	.763	.553	....
Propyl	C_3H_8O	3.883	2.918	2.256	1.779	1.405	1.130	.760	....
i-Propyl	C_3H_8O	4.565	3.246	2.370	1.757	1.331	1.029	.646	....
Butyric	$C_4H_{10}O$	5.186	3.873	2.948	2.267	1.782	1.411	.930	.540
Aromatics: Benzol	C_6H_6	.906	.763	.654	.567	.498	.444	.359	....
Toluene	C_7H_8	.772	.671	.590	.525	.471	.426	354	.278
Orthoxylene	C_8H_{10}	1.105	.937	.810	.709	.627	.560	.458	.352
Metaxylene	C_8H_{10}	.806	.702	.620	.552	.497	.451	.375	.296
Paraxylene	C_8H_{10}	solid	.738	.648	.574	.513	.463	.383	.300
Bromides: Ethyl	C_2H_5Br	.487	.441	.402	.368	....	....	....	....
Propyl	C_3H_7Br	.651	.582	.524	.475	.433	.397	.338	....
Ethylene	C_2H_4Br	2.438	2.039	1.721	1.475	1.286	1.131	.903	.678
Bromine	Br	1.267	1.120	1.005	.911	.830	.761	....	....
Chlorides: Ethylene	C_2H_4Cl	1.132	.966	.838	.736	.652	.584	.479	....
Chloroform	$CHCl_3$	.706	.633	.571	.519	.474	.435	....	....
Carbon-tetra	CCl_4	1.351	1.138	.975	.848	.746	.662	.534	....
Ethers: Diethyl	$C_4H_{10}O$	.294	.268	.245	.223	....	....	....	....
Methyl-propyl	$C_4H_{10}O$	.314	.285	.260	.237	....	....	....	....
Ethyl-propyl	$C_5H_{12}O$	.402	.360	.324	.294	.268	.245	....	....
Esters: Methylformate	$C_2H_4O_2$	.436	.391	.355	.325	....	....	....	....
Ethylformate	C_3H_6O	.510	.454	.408	.369	.336	.308	....	....
Methylacetate	$C_3H_6O_2$	.484	.431	.388	.352	.320	.293	....	....
Ethylacetate	$C_4H_8O_2$	.582	.512	.455	.407	.367	.333	.279	....
Iodides: Methyl	CH_3I	.606	.548	.500	.460	.424	....	....	....
Ethyl	C_2H_5I	.727	.654	.592	.540	.495	.456	.391	....
Propyl	C_3H_7I	.944	.833	.744	.669	.607	.552	.466	.371
Allyl	C_3H_5I	.936	.826	.734	.660	.597	.544	.458	.365
Paraffines: Pentane	C_5H_{12}	.289	.262	.240	.220	....	....	....	....
Hexane	C_6H_{14}	.401	.360	.326	.296	.271	.248	....	....
i-Hexane	C_6H_{14}	.376	.338	.306	.279	.254	.233	....	....
Heptane	C_7H_{16}	.524	.465	.416	.375	.341	.310	.262	....
i-Heptane	C_7H_{16}	.481	.428	.384	.347	.315	.288	.243	....
Octane	C_8H_{18}	.706	.616	.542	.483	.433	.391	.324	.252
Sulphides: Carbon di-	CS_2	.438	.405	.376	.352	.330	....	....	....
Turpentine	......	2.248	1.783	1.487	1.272	1.071	.926	.728	....

Table 176.—Fluidities of Gasolines and Kerosene (Temperature Variation)

(Henschel, Bur. Standards, Techn. Paper, 125, 1919.)

Sp. gr. 15°.6/15°.6	Temperature 5°C	15°C	25°C	35°C	45°C	55°C	Sp. gr. 15°.6/15°.6	Temperature 5°C	15°C	25°C	35°C	45°C	55°C
0.757	145	166	193	212	235	262	0.702	233	261	296	321	358	400
.748	130	151	170	194	214	243	.701	230	262	287	333	373	398
.743	129	156	185	203	227	...	.699	233	269	306	335	372	423
.726	202	233	264	293	324	360	.694	251	286	316	354	387	427
.722	189	219	244	278	308	342	.680	288	323	365	413	441	475
.716	197	217	256	289	321	341	.813 Kerosene	39	47	61	71	84	...
.708	203	230	257	292	232	260							

TABLE 177

PRESSURE EFFECT ON VISCOSITY OF PURE LIQUIDS

This table gives $\log_{10}$ of the relative viscosity as a function of pressure and density, the viscosity at 30°C and atmospheric pressure taken as unity. Bridgman, Proc. Amer. Acad., 61, 59, 1926, which see for further liquids. For each compound first line log η/η_0 at 30°C, second line at 75°C, third line η_{30}/η_{75}.

Substance	Pressure kg/cm² 1	500	1000	2000	4000	6000	8000	10000	12000	η_{30}
Methyl	.000	.094	.167	.286	.471	.616	.750	.874	.998	
alcohol...	9.769	9.862	9.933	.043	.208	.334	.448	.555	.655	.00520
	1.702	1.706	1.714	1.750	1.832	1.914	2.004	2.084	2.203	
Ethyl	.000	.107	.200	.363	.617	.829	1.023	1.211	1.390	
alcohol...	9.657	9.772	9.873	.045	.289	.473	.634	.778	.919	.01003
	2.203	2.163	2.123	2.080	2.128	2.270	2.449	2.710	2.958	
n-propyl	.000	.151	.283	.494	.836	1.131	1.402	1.667	1.915	
alcohol...	9.598	9.754	9.880	.074	.368	.610	.827	1.033	1.223	.01779
	2.523	2.495	2.529	2.630	2.938	3.319	3.758	4.305	4.920	
n-butyl	.000	.175	.321	.554	.934	1.289	1.609	1.912	2.208	
alcohol...	9.548	9.724	9.867	.089	.312	.690	.941	1.172	1.396	.02237
	2.845	2.838	2.858	2.932	3.343	3.991	4.679	5.521	6.518	
n-amyl.....	.000	.188	.341	.607	1.060	1.448	1.811	2.164	2.495	
alcohol...	9.540	9.723	9.871	.105	.466	.772	1.049	1.313	1.562	
	2.884	2.917	2.951	3.177	3.926	4.742	5.781	7.096	8.570	
	.000	.181	.315	.524	.847	1.112	1.360	1.615	1.846	
n-pentane...	9.811	.014	.163	.380	.676	.908	1.119	1.313	1.493	.00220
	1.545	1.469	1.419	1.393	1.483	1.600	1.742	2.004	2.254	
	.000	.184	.332	.561	.914	1.224	1.514	1.803		
n-hexane...	9.803	.028	.171	.379	.701	.961	1.198	1.426	1.646	.00296
	1.574	1.432	1.449	1.521	1.633	1.832	2.070	2.382		
Ethyl	.000	.134	.242	.405	.649	.837	1.008	1.172	1.323	
chloride..	9.850	.017	.131	.285	.514	.683	.834	.977	1.111	
	1.413	1.309	1.291	1.318	1.365	1.426	1.493	1.567	1.633	
Ethyl	.000	.121	.222	.387	.631	.854	1.043	1.223	1.400	
bromide..	9.806	9.959	.072	.235	.472	.653	.816	.978	1.123	.00368
	1.567	1.452	1.413	1.419	1.442	1.589	1.687	1.758	1.892	
Ethyl	.000	.115	.218	.385	.656	.888	1.108	1.330	1.549	
iodide....	9.837	9.954	.057	.227	.467	.672	.854	1.030	1.200	.00540
	1.455	1.449	1.445	1.439	1.545	1.644	1.795	1.995	2.234	
	.000	.135	.226	.373	.605	.804	.987	1.160		
Acetone....	9.895	.017	.113	.245	.445	.610	.762	.898	1.031	.00285
	1.274	1.312	1.297	1.343	1.445	1.563	1.679	1.828		
	.000	.134	.260	.497	.936	1.346	1.741	2.133		
Glycerine...	8.810	8.920	9.023	9.204	9.529	9.818	.094	.369	.628	3.8
	15.49	16.37	17.26	19.63	25.53	33.73	44.36	58.08		
	.000	.190	.351	.493 (1500) kg/cm²						
CCl_4.......	9.760	9.949	.100	.349	.542					.00845
	1.738	1.742	1.782							
	.000	.110	.211	.386	.660	.884				
Chloroform.	9.858	9.985	.094	.251	.480	.691	.914	1.141		.00519
	1.387	1.334	1.309	1.365	1.514	1.560				
	.000	.090	.160	.307	.509	.674	.840	1.010	1.189	
CS_2........	9.875	9.972	.051	.180	.372	.527	.671	.808	.946	.00352
	1.334	1.312	1.285	1.340	1.371	1.403	1.476	1.592	1.750	
	.000	.189	.324	.514	.792	1.042	1.261	1.469	1.670	
Ether......	9.878	.024	.149	.344	.601	.806	.986	1.155	1.311	.00212
	1.324	1.462	1.496	1.479	1.552	1.722	1.884	2.061	2.286	
	.000	.173	.347							
Benzene....	9.765	9.938	.081	.308	.498 (3000) kg/cm²					.00566
	1.718	1.718	1.845							
	.000	.145	.274	.497	.897	1.285	1.699	2.177		
Toluene....	9.796	9.939	.065	.267	.597	.896	1.186	1.504	1.832	.00523
	1.600	1.607	1.618	1.698	1.995	2.449	3.258	4.710		
	.000	.288	.541	1.081	2.273	3.007				
				1.652	(3000)	(5000)	kg/cm²			
Eugenol....	9.429	9.616	9.810	.143	.805	1.520	2.343			
	3.724	4.699	5.383	8.670	29.38					

TABLE 178

VISCOSITY OF MISCELLANEOUS LIQUIDS

Viscosities are given in cgs units, dyne-seconds per cm², or poises.

Liquid.	° C	Viscosity.	Reference.
Acetaldehyde	0.	0.00275	1
“	10.	0.00252	1
“	20.	0.00231	1
Air	−192.3	0.00172	2
Aniline	20.	0.04467	3
“	60.	0.0156	3
Bismuth	285.	0.0161	4
“	365.	0.0146	4
Copal lac	22.	4.80	5
Glycerine	2.8	42.2	6
“	14.3	13.87	6
“	20.3	8.30	6
“	26.5	4.94	6
“ 80.31% H_2O	8.5	1.021	6
“ 64.05% H_2O	8.5	0.222	6
“ 49.79% H_2O	8.5	0.092	6
Hydrogen, liquid	—	0.00011	2
Menthol, solid	14.9	2×10^{12}	7
“ liquid	56.9	0.069	7
Mercury	−20.	0.0184	8
“	0.	0.01661	4
“	20.	0.01547	4
“	34.	0.01476	4
“	98	0.01263	4
“	193.	0.01079	4
“	299.	0.00975	4
Oils:			
Dogfish-liver .923 ‡	30.	0.414	9
“ “ .918	50.	0.211	9
“ “ .908	90.	0.080	9
Linseed .925	30.	0.331	9
“ .922	50	0.176	9
“ .914	90.	0.071	9
* Spindle oil .885	15.6	0.453	10
“ “	37.8	0.162	10
“ “	100.0	0.033	10
* Light machinery .907 ‡	15.6	1.138	10
* Light machinery	37.8	0.342	10
“ “	100.0	0.049	10
* “Solar red” engine	15.6	1.915	10
“ “ “	37.8	0.496	10
“ “ “	100.0	0.058	10
* “Bayonne” engine	15.6	2.172	10
“ “	37.8	0.572	10
* “ “	100.0	0.063	10
* “Queen's red” engine	15.6	2.995	10
“ “ “	37.8	0.711	10
“ “ “	100.0	0.070	10
* “Galena” axle oil	15.6	4.366	10
* “ “ “	37.8	0.909	10
* Heavy machinery	15.6	6.606	10
“ “	37.8	1.274	10
* Filtered cylinder	37.8	2.406	10
“ “	100.0	0.187	10
* Dark cylinder	37.8	4.224	10
“ “	100.0	0.240	10
* Dark cylinder	37.8	7.324	10
“ “	100.0	0.341	10
* “Extra L. L.”	37.8	11.156	10
“ “ “	100.0	0.451	10
Linseed .925 ‡	30.	0.331	9
“ .922	50.	0.176	9
“ .914	90.	0.071	9
Olive .9195	10.	1.38	11
“	15.	1.075	11
“ .9130	20.	0.840	11
“ .9065	30.	0.540	11
“ .9000	40.	0.363	11
“ .8935	50.	0.258	11
“ .8800	70.	0.124	11
† Rape	15.6	1.118	10
“	37.8	0.422	10
“	100.0	0.080	10
“ (another)	15.6	1.176	10
“ (another)	100.0	0.085	10
Soya bean .919 ‡	30.0	0.406	9
“ “ .915	50.0	0.206	9
“ “ .906	90.0	0.078	9
† Sperm	15.6	0.420	10
“	37.8	0.185	10
“	100.0	0.046	10
Paraffins:			
Pentane	21.0	0.0026	12
Hexane	23.7	0.0033	12
Heptane	24.0	0.0045	12
Octane	22.2	0.0053	12
Nonane	22.3	0.0062	12
Decane	22.3	0.0077	12
Undecane	22.7	0.0095	12
Dodecane	23.3	0.0126	12
Tridecane	23.3	0.0155	12
Tetradecane	21.9	0.0213	12
Pentadecane	22.0	0.0281	12
Hexadecane	22.2	0.0359	12
Phenol	18.3	0.1274	13
“	90.0	0.0126	13
Sulphur	170.	320.0	14
“	180.	550.0	14
“	187.	560.0	14
“	200.	500.0	14
“	250.	104.0	14
“	300.	24.0	14
“	340.	6.2	14
“	380.	2.5	14
“	420.	1.13	14
“	448.	0.80	14
† Tallow	66.	0.176	10
“	100.	0.078	10
Zinc	280.	0.0168	4
“	357.	0.0142	4
“	389.	0.0131	4

* American mineral oils; based on water as .01028 at 20° C. † Based on water as per 1st footnote. ‡ Densities.
References: (1) Thorpe and Rodger, 1894–7; (2) Verschaffelt, Sc. Ab. 1917; (3) Wijkander, 1879; (4) Plüss. Z. An. Ch. 93, 1915; (5) Metz, C. R. 1903; (6) Schöttner, Wien. Ber. 77, 1878, 79, 1879; (7) Heydweiller, W. Ann. 63, 1897; (8) Koch, W. Ann. 14, 1881; (9) White, Bul. Bur. Fish. 32, 1912; (10) Archbutt-Deeley, Lubrication and Lubricants, 1912; (11) Higgins, Nat. Phys. Lab. 11, 1914; (12) Bartolli, Stracciati, 1885–6; (13) Scarpa, 1903–4; (14) Rotinganz, Z. Ph. Ch. 62, 1908.

Ratio of Viscosity at High to that at Atmospheric Pressure.

Pressure tons/in²	Kg/cm²	Bayonne oil (mineral)	FFF cylinder (mineral)	Trotter (animal)	Rape (vegetable)	castor (vegetable)	Sperm (fish)
1	157.5	1.3	1.4	1.2	1.1	1.2	1.2
2	315.	2.0	2.0	1.6	1.4	1.6	1.5
4	630.	4.0	4.5	2.4	2.3	2.7	2.4
6	945.	7.8	8.9	3.5	3.5	4.2	3.5
8	1260.	16.1	—	5.0	—	5.8	—

Hyde, Pr. Roy. Soc. 97A, 240, 1920.

Table 179

SPECIFIC VISCOSITY OF SOLUTIONS

(Density and temperature variation)

This table shows the effect of change of concentration and change of temperature on the viscosity of solutions of salts in water. The specific viscosity × 100 is given for one or more densities and for several temperatures in the case of each solution. μ stands for specific viscosity, and t for temperature Centigrade.

(Abridged from earlier editions of these tables.)

Salt	Percentage by weight of salt in solution	Density	μ	t	μ	t	μ	t	μ	t	Authority
$BaCl_2$	7.60	.....	77.9	10	44.0	30	35.2	50	.....	..	Sprung
"	24.34	.....	100.7	"	66.2	"	47.7	"	.....	..	"
$Ba(NO_3)_2$	2.98	1.027	62.0	15	51.1	25	42.4	35	34.8	45	Wagner
$CaCl_2$	15.17	.....	110.9	10	71.3	30	50.3	50	.....	..	"
"	31.60	.....	272.5	"	177.0	"	124.0	"	.....	..	Sprung
"	39.75	.....	670.0	"	379.0	"	245.5	"	.....	..	"
"	44.09	.....	.....	..	593.1	"	363.2	"	.....	..	"
$Ca(NO_3)_2$	17.55	1.171	93.8	15	74.6	25	60.0	35	49.9	45	Wagner
"	40.13	1.386	242.6	"	217.1	"	156.5	"	128.1	"	"
$CdCl_2$	11.09	1.109	77.5	"	60.5	"	49.1	"	40.7	"	"
$Cd(NO_3)_2$	7.81	1.074	61.9	"	50.1	"	41.1	"	34.0	"	"
"	22.36	1.241	85.1	"	69.0	"	57.3	"	47.5	"	"
$CoCl_2$	7.97	1.081	83.0	"	65.1	"	53.6	"	44.9	"	"
"	22.27	1.264	161.6	"	126.6	"	101.6	"	85.6	"	"
$Co(NO_3)_2$	8.28	1.073	74.7	"	57.9	"	48.7	"	39.8	"	"
"	24.53	1.229	110.4	"	88.0	"	71.5	"	59.1	"	"
$CuCl_2$	12.01	1.104	87.2	"	67.8	"	55.1	"	45.6	"	"
"	21.35	1.215	121.5	"	95.8	"	77.0	"	63.2	"	"
"	33.03	1.331	178.4	"	137.2	"	107.6	"	87.1	"	"
$Cu(NO_3)_2$	18.99	1.177	97.3	"	76.0	"	61.5	"	51.3	"	"
"	46.71	1.536	382.9	"	283.8	"	215.3	"	172.2	"	"
$CuSO_4$	6.79	1.055	79.6	"	61.8	"	49.8	"	41.4	"	"
"	12.57	1.115	98.2	"	74.0	"	59.7	"	52.0	"	"
"	17.49	1.163	124.5	"	96.8	"	75.9	"	61.8	"	"
HCl	8.14	1.037	71.0	"	57.9	"	48.3	"	40.1	"	"
"	16.12	1.084	80.0	"	66.5	"	56.4	"	48.1	"	"
"	23.04	1.114	91.8	"	79.9	"	65.9	"	56.4	"	"
$HgCl_2$	3.55	1.033	76.75	10	59.2	20	46.6	30	38.3	40	"
HNO_3	8.37	1.067	66.4	15	54.8	25	45.4	35	37.6	45	"
"	12.20	1.116	69.5	"	57.3	"	47.9	"	40.7	"	"
"	28.31	1.178	80.3	"	65.5	"	54.9	"	46.2	"	"
H_2SO_4	7.87	1.065	77.8	"	61.0	"	50.0	"	41.7	"	"
"	15.50	1.130	95.1	"	75.0	"	60.5	"	49.8	"	"
"	23.43	1.200	122.7	"	95.5	"	77.5	"	64.3	"	"
KCl	10.23	.....	70.0	10	46.1	30	33.1	50	.....	..	Sprung
"	22.21	.....	70.0	"	48.6	"	36.4	"	.....	..	"
KBr	23.16	.....	66.2	"	44.7	"	33.2	"	.....	..	"
"	34.64	.....	66.6	"	47.0	"	35.7	"	.....	..	"
KI	8.42	.....	69.5	"	44.0	"	31.3	"	.....	..	"
"	33.03	.....	61.8	"	42.9	"	32.4	"	.....	..	"
"	54.00	.....	68.8	"	48.5	"	37.6	"	.....	..	"
$KClO_3$	5.69	.....	.....	..	45.0	"	31.4	"	.....	..	"
KNO_3	6.32	.....	70.8	"	44.6	"	31.8	"	.....	..	"
"	17.60	.....	68.8	"	46.0	"	33.4	"	.....	..	"
K_2SO_4	5.17	.....	77.4	"	48.6	"	34.3	"	.....	..	"
"	9.77	.....	81.0	"	52.0	"	36.9	"	.....	..	"
K_2CrO_4	11.93	.....	75.8	"	62.5	"	41.0	40	.....	..	"
"	32.78	.....	109.5	"	88.9	"	62.6	"	.....	..	"
$K_2Cr_2O_7$	6.97	1.049	73.1	"	56.4	20	45.5	30	37.7	40	Slotte
$Mg(NO_3)_2$	18.62	1.102	99.8	15	81.3	25	66.5	35	56.2	45	Wagner
"	39.77	1.430	317.0	"	250.0	"	191.4	"	158.1	"	"
$MgSO_4$	4.98	.....	96.2	10	59.0	30	40.9	50	.....	..	Sprung
"	19.32	.....	302.2	"	166.4	"	106.0	"	.....	..	"
$MnCl_2$	8.01	1.096	92.8	15	71.1	25	57.5	35	48.1	45	Wagner
"	40.13	1.453	537.3	"	393.4	"	300.4	"	246.5	"	"

SPECIFIC VISCOSITY OF SOLUTIONS

(Density and temperature variation)
(Abridged from earlier editions)

Salt	Percentage by weight of salt in solution	Density	μ	t	μ	t	μ	t	μ	t	Authority
$Mn(NO_3)_2$	18.31	1.148	96.0	15	76.4	25	64.5	35	55.6	45	Wagner
"	49.31	1.506	396.8	"	301.1	"	221.0	"	188.8	"	"
$MnSO_4$	11.45	1.147	129.4	"	98.6	"	78.3	"	63.4	"	"
"	22.08	1.306	661.8	"	474.3	"	347.9	"	266.8	"	"
NaCl	7.95	.....	82.4	10	52.0	30	31.8	50	.....	..	Sprung
"	14.31	.....	94.8	"	60.1	"	36.9	"	.....	..	"
"	23.22	.....	128.3	"	79.4	"	47.4	"	.....	..	"
NaBr	9.77	.....	75.6	"	48.7	"	34.4	"	.....	..	"
"	18.58	.....	82.6	"	53.5	"	38.2	"	.....	..	"
"	27.27	.....	95.9	"	61.7	"	43.8	"	.....	..	"
NaI	8.83	.....	73.1	"	46.0	"	32.4	"	.....	..	"
"	17.15	.....	73.8	"	47.4	"	33.7	"	.....	..	"
"	55.47	.....	157.2	"	96.4	"	66.9	"	.....	..	"
$NaClO_3$	11.50	.....	78.7	"	50.0	"	35.3	"	.....	..	"
"	33.54	.....	121.0	"	75.7	"	53.0	"	.....	..	"
$NaNO_3$	7.25	.....	75.6	"	47.9	"	33.8	"	.....	..	"
"	18.20	.....	87.0	"	55.9	"	39.3	"	.....	..	"
"	31.55	.....	121.2	"	76.2	"	53.4	"	.....	..	"
Na_2SO_4	4.98	.....	96.2	"	59.0	"	40.9	"	.....	..	"
"	14.03	.....	187.9	"	107.4	"	71.1	"	.....	..	"
"	19.32	.....	302.2	"	166.4	"	106.0	"	.....	..	"
Na_2CrO_4	10.62	1.112	103.3	"	79.3	"	63.5	30	52.3	40	Slotte
"	14.81	1.164	127.5	"	97.1	"	77.3	"	63.0	"	"
NH_4Cl	3.67	.....	71.5	"	45.0	"	31.9	50	.....	..	Sprung
"	15.68	.....	67.3	"	46.2	"	34.0	"	.....	..	"
"	23.37	.....	67.4	"	47.7	"	36.1	"	.....	..	"
NH_4Br	15.97	.....	65.2	"	43.2	"	31.5	"	.....	..	"
"	36.88	.....	62.4	"	44.6	"	34.3	"	.....	..	"
NH_4NO_3	5.97	.....	69.6	"	44.3	"	31.6	"	.....	..	"
"	27.08	.....	67.0	"	47.7	"	34.9	"	.....	..	"
"	49.83	.....	81.1	"	63.3	"	48.9	"	.....	..	"
$(NH_4)_2SO_4$	8.10	.....	107.9	"	52.3	"	37.0	"	.....	..	"
"	25.51	.....	148.4	"	74.8	"	54.1	"	.....	..	"
$(NH_4)_2CrO_4$	19.75	1.120	88.2	"	70.0	20	57.8	30	48.4	..	Slotte
"	28.04	1.173	101.1	"	80.7	"	60.8	"	56.4	..	"
$(NH_4)_2Cr_2O_7$	13.00	1.078	72.6	"	57.2	"	46.8	"	39.1	40	"
"	19.93	1.126	77.6	"	58.8	"	48.7	"	40.9	"	"
$NiCl_2$	11.45	1.109	90.4	15	70.0	25	57.5	35	48.2	45	Wagner
"	30.40	1.337	229.5	"	171.8	"	139.2	"	111.9	"	"
$Ni(NO_3)_2$	16.49	1.136	90.7	"	70.1	"	57.4	"	48.9	"	"
"	40.95	1.388	222.6	"	169.7	"	128.2	"	152.4	"	"
$Pb(NO_3)_2$	17.93	1.179	74.0	"	59.1	"	48.5	"	40.3	"	"
"	32.22	1.362	91.8	"	72.5	"	59.6	"	50.6	"	"
$Sr(NO_3)_2$	10.29	1.088	69.3	"	56.0	"	45.9	"	39.1	"	"
"	32.61	1.307	116.9	"	93.3	"	76.7	"	62.3	"	"
$ZnCl_2$	15.33	1.146	93.6	"	72.7	"	57.8	"	48.2	"	"
"	23.49	1.229	111.5	"	86.6	"	69.8	"	57.5	"	"
"	33.78	1.343	151.7	"	117.9	"	90.0	"	72.6	"	"
$Zn(NO_3)_2$	15.95	1.115	80.7	"	64.3	"	52.6	"	43.8	"	"
"	30.23	1.229	104.7	"	85.7	"	69.5	"	57.7	"	"
"	44.50	1.437	167.9	"	130.6	"	105.4	"	87.9	"	"
$ZnSO_4$	7.12	1.106	97.1	"	79.3	"	62.7	"	51.5	"	"
"	16.64	1.195	156.0	"	118.6	"	94.2	"	73.5	"	"
"	23.09	1.281	232.8	"	177.4	"	135.2	"	108.1	"	"

Table 180

SPECIFIC VISCOSITY OF SOLUTIONS (VARIOUS CONCENTRATIONS, 25°C)

Dissolved salt.	Normal solution.		½ normal.		¼ normal.		⅛ normal.		Authority.
	Density.	Specific viscosity.	Density.	Specific viscosity.	Density.	Specific viscosity.	Density.	Specific viscosity.	
Acids: Cl_2O_3	1.0562	1.012	1.0283	1.003	1.0143	1.000	1.0074	0.999	Reyher
HCl	1.0177	1.067	1.0092	1.034	1.0045	1.017	1.0025	1.009	"
$HClO_3$	1.0485	1.052	1.0244	1.025	1.0126	1.014	1.0064	1.006	"
HNO_3	1.0332	1.027	1.0168	1.011	1.0086	1.005	1.0044	1.003	"
H_2SO_4	1.0303	1.090	1.0154	1.043	1.0074	1.022	1.0035	1.008	Wagner
Aluminium sulphate	1.0550	1.406	1.0278	1.178	1.0138	1.082	1.0068	1.038	"
Barium chloride	1.0884	1.123	1.0441	1.057	1.0226	1.026	1.0114	1.013	"
" nitrate	–	–	1.0518	1.044	1.0259	1.021	1.0130	1.008	"
Calcium chloride	1.0446	1.156	1.0218	1.076	1.0105	1.036	1.0050	1.017	"
" nitrate	1.0596	1.117	1.0300	1.053	1.0151	1.022	1.0076	1.008	"
Cadmium chloride	1.0779	1.134	1.0394	1.063	1.0197	1.031	1.0098	1.020	"
" nitrate	1.0954	1.165	1.0479	1.074	1.0249	1.038	1.0119	1.018	"
" sulphate	1.0973	1.348	1.0487	1.157	1.0244	1.078	1.0120	1.033	"
Cobalt chloride	1.0571	1.204	1.0286	1.097	1.0144	1.048	1.0058	1.023	"
" nitrate	1.0728	1.166	1.0369	1.075	1.0184	1.032	1.0094	1.018	"
" sulphate	1.0750	1.354	1.0383	1.160	1.0193	1.077	1.0110	1.040	"
Copper chloride	1.0624	1.205	1.0313	1.098	1.0158	1.047	1.0077	1.027	"
" nitrate	1.0755	1.179	1.0372	1.080	1.0185	1.040	1.0092	1.018	"
" sulphate	1.0790	1.358	1.0402	1.160	1.0205	1.080	1.0103	1.038	"
Lead nitrate	1.1380	1.101	0.0699	1.042	1.0351	1.017	1.0175	1.007	"
Lithium chloride	1.0243	1.142	1.0129	1.066	1.0062	1.031	1.0030	1.012	"
" sulphate	1.0453	1.290	1.0234	1.137	1.0115	1.065	1.0057	1.032	"
Magnesium chloride	1.1375	1.201	1.0188	1.094	1.0091	1.044	1.0043	1.021	"
" nitrate	1.0512	1.171	1.0259	1.082	1.0130	1.040	1.0066	1.020	"
" sulphate	1.0584	1.367	1.0297	1.164	1.0152	1.078	1.0076	1.032	"
Manganese chloride	1.0513	1.209	1.0259	1.098	1.0125	1.048	1.0063	1.023	"
" nitrate	1.0690	1.183	1.0349	1.087	1.0174	1.043	1.0093	1.023	"
" sulphate	1.0728	1.364	1.0365	1.169	1.0179	1.076	1.0087	1.037	"
Nickel chloride	1.0591	1.205	1.0308	1.097	1.0144	1.044	1.0067	1.021	"
" nitrate	1.0755	1.180	1.0381	1.084	1.0192	1.042	1.0096	1.019	"
" sulphate	1.0773	1.361	1.0391	1.161	1.0198	1.075	1.0017	1.032	"
Potassium chloride	1.0466	0.987	1.0235	0.987	1.0117	0.990	1.0059	0.993	"
" chromate	1.0935	1.113	1.0475	1.053	1.0241	1.022	1.0121	1.012	"
" nitrate	1.0605	0.975	1.0305	0.982	1.0161	0.987	1.0075	0.992	"
" sulphate	1.0664	1.105	1.0338	1.049	1.0170	1.021	1.0084	1.008	"
Sodium chloride	1.0401	1.097	1.0208	1.047	1.0107	1.024	1.0056	1.013	Reyher
" bromide	1.0786	1.064	1.0396	1.030	1.0190	1.015	1.0100	1.008	"
" chlorate	1.0710	1.090	1.0359	1.042	1.0180	1.022	1.0092	1.012	"
" nitrate	1.0554	1.065	1.0281	1.026	1.0141	1.012	1.0071	1.007	"
Silver nitrate	1.1386	1.058	1.0692	1.020	1.0348	1.006	1.0173	1.000	Wagner
Strontium chloride	1.0676	1.141	1.0336	1.067	1.0171	1.034	1.0084	1.014	"
" nitrate	1.0822	1.115	1.0419	1.049	1.0208	1.024	1.0104	1.011	"
Zinc chloride	1.0590	1.189	1.0302	1.096	1.0152	1.053	1.0077	1.024	"
" nitrate	1.0758	1.164	1.0404	1.086	1.0191	1.039	1.0096	1.019	"
" sulphate	1.0792	1.367	1.0402	1.173	1.0198	1.082	1.0094	1.036	"

* In the case of solutions of salts it has been found (*vide* Arrhennius, Zeits. für Phys. Chem. vol. 1, p. 285) that the specific viscosity can, in many cases, be nearly expressed by the equation $\mu = \mu_1^n$, where μ_1 is the specific viscosity for a normal solution referred to the solvent at the same temperature, and n the number of gramme molecules in the solution under consideration. The same rule may of course be applied to solutions stated in percentages instead of gramme molecules. The table here given has been compiled from the results of Reyher (Zeits. für Phys. Chem. vol. 2, p. 749) and of Wagner (Zeits. für Phys. Chem. vol. 5, p. 31) and illustrates this rule. The numbers are all for 25° C.

TABLE 181

VISCOSITY OF GASES AND VAPORS

The values of μ given in the table are 10^6 times the coefficients of viscosity in c.g.s. units.

Substance.	Temp. ° C	μ	Reference.
Acetone	18.0	78.	1
Air *	−21.4	163.9	2
"	0.0	173.3	2
"	15.0	180.7	2
"	99.1	220.3	2
"	182.4	255.9	2
"	302.0	299.3	2
Alcohol, Methyl	66.8	135.	3
Alcohol, Ethyl	78.4	142.	3
Alcohol, Propyl, norm.	97.4	142.	3
Alcohol, Isopropyl	82.8	162.	3
Alcohol, Butyl, norm.	116.9	143.	3
Alcohol, Isobutyl	108.4	144.	3
Alcohol, Tert. butyl.	82.9	160.	3
Ammonia	0.0	96.	4
"	20.0	108.	4
Argon	0.0	210.4	5
"	14.7	220.8	5
"	17.9	224.1	5
"	99.7	273.3	5
"	183.7	322.1	5
Benzene	0.	70.	10
"	19.0	79.	6
"	100.0	118.	6
Carbon bisulphide	16.9	92.4	1
Carbon dioxide	−20.7	129.4	2
" "	0.	142.	10
" "	15.0	145.7	2
" "	99.1	186.1	2
" "	182.4	222.1	2
" "	302.0	268.2	2
Carbon monoxide	0.0	163.0	10
" "	20.0	184.0	4
Chlorine	0.0	128.7	4
"	20.0	147.0	4
Chloroform	0.0	95.9	1
"	17.4	102.9	1
"	61.2	189.0	3
Ether	0.0	68.9	1
Ether	16.1	73.2	1
"	36.5	79.3	1
Ethyl chloride	0.	93.5	4
Ethyl iodide	72.3	216.0	3
Ethylene	0.0	96.1	2
Helium	0.0	189.1	5
"	15.3	196.9	5
"	66.6	234.8	5
"	184.6	269.9	5
Hydrogen	−20.6	81.9	2
"	0.0	86.7	10
"	15.	88.9	2
"	99.2	105.9	2
"	182.4	121.5	2
"	302.0	139.2	2
Krypton	15.0	246.	11
Mercury	270.0	489.†	8
"	300.0	532.†	8
"	330.0	582.†	8
"	360.0	627.†	8
"	390.0	671.†	8
Methane	20.0	120.1	4
Methyl chloride	0.0	98.8	2
" "	15.0	105.2	2
" "	302.0	213.9	2
Methyl iodide	44.0	232.	3
Nitrogen	−21.5	156.3	7
"	0.	166.	10
"	10.9	170.7	7
"	53.5	189.4	7
Nitric oxide	0.	179.	10
Nitrous oxide	0.	138.	10
Oxygen	0.	189.	10
"	15.4	195.7	7
"	53.5	215.9	7
Water Vapor	0.0	90.4	1
" "	16.7	96.7	1
" "	100.0	132.0	9
Xenon	15.	222.	11

1 Puluj, Wien. Ber. 69 (2), 1874.
2 Breitenbach, Ann. Phys. 5, 1901.
3 Steudel, Wied. Ann. 16, 1882.
4 Graham, Philos. Trans. Lond. 1846, III.
5 Schultze, Ann. Phys. (4), 5, 6, 1901.
6 Schumann, Wied. Ann. 23, 1884.
7 Obermayer, Wien. Ber. 71 (2a), 1875.
8 Koch, Wied. Ann. 14, 1881, 19, 1883.
9 Meyer-Schumann, Wied. Ann. 13, 1881.
10 Jeans, assumed mean, 1916.
11 Rankine, 1910.
12 Vogel (Eucken, Phys. Z. 14, 1913). For summaries see: Fisher, Phys. Rev. 24, 1904; Chapman, Phil. Tr. A. 211, 1911; Gilchrist, Phys. Rev. 1, 1913. Schmidt, Ann. d. Phys. 30, 1909.

* Gilchrist's value of the viscosity of air may be taken as the most accurate at present available. His value at 20.2° C is 1.812×10^{-4}. The temperature variation given by Holman (Phil. Mag. 1886) gives $\mu = 1715.50 \times 10^{-7}(1 + .00275t - .00000034t^2)$. See Phys. Rev. 1, 1913. Millikan (Ann. Phys. 41, 759, 1913) gives for the most accurate value $\mu_t = 0.00018240 - 0.000000493(23 - t)$ when $(23 > t > 12)$ whence $\mu_{20} = 0.0001809 \pm 0.1\%$. For μ_0 he gives 0.0001711.

† The values here given were calculated from Koch's table (Wied. Ann. 19, p. 869, 1883) by the formula $\mu = 489\,[1 + 746(t - 270)]$.

Table 182

VISCOSITY OF GASES

Variation of Viscosity with Pressure and Temperature

According to the kinetic theory of gases the coefficient of viscosity $\mu = \frac{1}{3}(\rho\bar{c}l)$, ρ being the density, $\bar{c}$ the average velocity of the molecules, l the average path. Since l varies inversely as the number of molecules per unit volume, ρl is a constant and μ should be independent of the density and pressure of a gas (Maxwell's law). This has been found true for ordinary pressures; below $\frac{1}{60}$ atmosphere it may fail, and for certain gases it has been proved untrue for high pressures, e.g., CO_2 at 33° and above 50 atm. See Jeans, "Dynamical Theory of Gases."

If B is the amount of momentum transferred from a plane moving with velocity U and parallel to a stationary plane distant d, and s is a quantity (coefficient of slip) to allow for the slipping of the gas molecules over the plane, then $\mu = (B/U)\,(d + 2s)$; s is of the same magnitude as l, probably between .7 (Timiriazeff) and .9 (Knudsen) of it; at low pressures d becomes negligible compared with $2s$ and the viscosity should vary inversely as the pressure.

$\bar{c}$ depends only on the temperature and the molecular weight. $\bar{c}$ varies as the $\sqrt{T}$, but μ has been found to increase much more rapidly. Meyer's formula, $\mu_t = \mu_0(1 + at)$, where a is a constant and μ_0 the viscosity at 0° C, is a convenient approximate relation. Sutherland's formula (Phil. Mag. 31, 1893),

$$\mu_t = \mu_o \frac{273 + C}{T + C}\left(\frac{T}{273}\right)^{\frac{3}{2}},$$

is the most accurate formula in use, taking in account the effect of molecular forces. It holds for temperatures above the critical and for pressures following approximately Boyle's law. It may be thrown into the form $T = KT^{\frac{3}{2}}/\mu - C$ which is linear in terms of T and $T^{\frac{3}{2}}/\mu$, with a slope equal to K and the ordinate intercept equal to $-C$. See Fisher, Phys. Rev. 24, 1907, from which most of the following table is taken. Onnes (see Jeans) shows that this formula does not represent Helium at low temperatures with anything like the accuracy of the simpler formula $\mu = \mu_0(T/273.1)^n$.

The following table contains the constants for the above three formulae, T being always the absolute temperature, Centigrade scale.

Gas.	C	$K \times 10^7$	a	n *	Gas.	C	$K \times 10^7$	a	n *
Air	124	150	—	.754	Hydrogen	72	66	—	.69
Argon	172	206	—	.819	Krypton	188	—	—	—
Carbon monoxide	102	135	.00269	.74	Neon	252	—	—	—
Carbon dioxide	240	158	.00348	.98	Nitrogen	110	143	.00269	.74
Chloroform	454	159	—	—	Nitrous oxide, N_2O	313	172	.00345	.93
Ethylene	226	106	.00350	—	Oxygen	131	176	—	.79
Helium	80	148	—	.683	Xenon	252	—	—	—
Helium	—	—	—	.647					

* The authorities for n are: Air, Rayleigh; Ar, Mean, Rayleigh, Schultze; CO, CO_2, N_2, N_2O, von Obermayer; Helium, Mean, Rayleigh, Schultze; 2d value, low temperature work of Onnes; H_2, O_2, Mean, Rayleigh, von Obermayer.

DIFFUSION OF AN AQUEOUS SOLUTION INTO PURE WATER

If k is the coefficient of diffusion, dS the amount of the substance which passes in the time dt, at the place x, through q sq. cm of a diffusion cylinder under the influence of a drop of concentration dc/dx, then

$$dS = -kq \frac{dc}{dx} dt.$$

k depends on the temperature and the concentration. c gives the gram-molecules per liter. The unit of time is a day.

Substance.	c	t°	k	Reference	Substance.	c	t°	k	Reference.
Bromine	0.1	12.	0.8	1	Calcium chloride	0.864	8.5	0.70	4
Chlorine	"	12.	1.22	"	" "	1.22	9.	0.72	"
Copper sulphate	"	17.	0.39	2	" "	0.060	9.	0.64	"
Glycerine	"	10.14	0.357	3	" "	0.047	9.	0.68	"
Hydrochloric acid	"	19.2	2.21	2	Copper sulphate	1.95	17.	0.23	2
Iodine	"	12.	(0.5)	1	" "	0.95	17.	0.26	"
Nitric acid	"	19.5	2.07	2	" "	0.30	17.	0.33	"
Potassium chloride	"	17.5	1.38	2	" "	0.005	17.	0.47	"
" hydroxide	"	13.5	1.72	2	Glycerine	2/8	10.14	0.354	3
Silver nitrate	"	12.	0.985	2	"	6/8	10.14	0.345	"
Sodium chloride	"	15.0	0.94	2	"	10/8	10.14	0.329	"
Urea	"	14.8	0.97	3	"	14/8	10.14	0.300	"
Acetic acid	0.2	13.5	0.77	4	Hydrochloric acid	4.52	11.5	2.93	4
Barium chloride	"	8.	0.66	4	" "	3.16	11.	2.67	"
Glycerine	"	10.1	3.55	3	" "	0.945	11.	2.12	"
Sodium actetate	"	12.	0.67	5	" "	0.387	11.	2.02	"
" chloride	"	15.0	0.94	2	" "	0.250	11.	1.84	"
Urea	"	14.8	0.969	3	Magnesium sulphate	2.18	5.5	0.28	4
Acetic acid	1.0	12.	0.74	6	" "	0.541	5.5	0.32	"
Ammonia	"	15.23	1.54	7	" "	3.23	10.	0.27	"
Formic acid	"	12.	0.97	7	" "	0.402	10.	0.34	"
Glycerine	"	10.14	0.339	3	Potassium hydroxide	0.75	12.	1.72	6
Hydrochloric acid	"	12.	2.09	6	" "	0.49	12.	1.70	"
Magnesium sulphate	"	7.	0.30	4	" "	0.375	12.	1.70	"
Potassium bromide	"	10.	1.13	8	" nitrate	3.9	17.6	0.89	2
" hydroxide	"	12	1.72	6	" "	1.4	17.6	1.10	"
Sodium chloride	"	15.0	0.94	2	" "	0.3	17.6	1.26	"
" "	"	14.3	0.964	3	" "	0.02	17.6	1.28	"
" hydroxide	"	12.	1.11	2	" sulphate	0.95	19.6	0.79	"
" iodide	"	10.	0.80	8	" "	0.28	19.6	0.86	"
Sugar	"	12.	0.254	6	" "	0.05	19.6	0.97	"
Sulphuric acid	"	12.	1.12	6	" "	0.02	19.6	1.01	"
Zinc sulphate	"	14.8	0.236	9	Silver nitrate	3.9	12.	0.535	"
Acetic acid	2.0	12	0.69	6	" "	0.9	12.	0.88	"
Calcium chloride	"	10.	0.68	8	" "	0.02	12.	1.035	"
Cadmium sulphate	"	19.04	0.246	9	Sodium chloride	2/8	14.33	1.013	3
Hydrochloric acid	"	12.	2.21	6	" "	4/8	14.33	0.996	"
Sodium iodide	"	10.	0.90	8	" "	6/8	14.33	0.980	2
Sulphuric acid	"	12.	1.16	6	" "	10/8	14.33	0.948	"
Zinc acetate	"	18.05	0.210	9	" "	14/8	14.33	0.917	"
" "	"	0.04	0.120	9	Sulphuric acid	9.85	18.	2.36	2
Acetic acid	3.0	12.	0.68	–	" "	4.85	18.	1.90	"
Potassium carbonate	"	10.	0.60	8	" "	2.85	18.	1.60	"
" hydroxide	"	12.	1.89	6	" "	0.85	18.	1.34	"
Acetic acid	4.0	12.	0.66	6	" "	0.35	18.	1.32	"
Potassium chloride	"	10.	1.27	8	" "	0.005	18.	1.30	"

1 Euler, Wied. Ann. 63, 1897.
2 Thovert, C. R. 133, 1901; 134, 1902.
3 Heimbrodt, Diss. Leipzig, 1903.
4 Scheffer, Chem. Ber. 15, 1882; 16, 1883; Zeitschr. Phys Chem. 2, 1888.
5 Kawalki, Wied. Ann. 52, 1894; 59, 1896.
6 Arrhenius. Zeitschr. Phys. Chem. 10, 1892.
7 Abegg, Zeitschr. Phys. Chem. 11, 1893.
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9 Seitz, Wied. Ann. 64, 1898

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen

TABLE 184

DIFFUSION OF VAPORS

Coefficients of diffusion of vapors in C. G. S. units. The coefficients are for the temperatures given in the table and a pressure of 76 centimeters of mercury.*

Vapor.	Temp. C. °	k_t for vapor diffusing into hydrogen.	k_t for vapor diffusing into air.	k_t for vapor diffusing into carbon dioxide.
Acids: Formic	0.0	0.5131	0.1315	0.0879
"	65.4	0.7873	0.2035	0.1343
"	84.9	0.8830	0.2244	0.1519
Acetic	0.0	0.4040	0.1061	0.0713
"	65.5	0.6211	0.1578	0.1048
"	98.5	0.7481	0.1965	0.1321
Isovaleric	0.0	0.2118	0.0555	0.0375
"	98.0	0.3934	0.1031	0.0696
Alcohols: Methyl	0.0	0.5001	0.1325	0.0880
"	25.6	0.6015	0.1620	0.1046
"	49.6	0.6738	0.1809	0.1234
Ethyl	0.0	0.3806	0.0994	0.0693
"	40.4	0.5030	0.1372	0.0898
"	66.9	0.5430	0.1475	0.1026
Propyl	0.0	0.3153	0.0803	0.0577
"	66.9	0.4832	0.1237	0.0901
"	83.5	0.5434	0.1379	0.0976
Butyl	0.0	0.2716	0.0681	0.0476
"	99.0	0.5045	0.1265	0.0884
Amyl	0.0	0.2351	0.0589	0.0422
"	99.1	0.4362	0.1094	0.0784
Hexyl	0.0	0.1998	0.0499	0.0351
"	99.0	0.3712	0.0927	0.0651
Benzene	0.0	0.2940	0.0751	0.0527
"	19.9	0.3409	0.0877	0.0609
"	45.0	0.3993	0.1011	0.0715
Carbon disulphide	0.0	0.3690	0.0883	0.0629
" "	19.9	0.4255	0.1015	0.0726
" "	32.8	0.4626	0.1120	0.0789
Esters: Methyl acetate	0.0	0.3277	0.0840	0.0557
" "	20.3	0.3928	0.1013	0.0679
Ethyl "	0.0	0.2373	0.0630	0.0450
" "	46.1	0.3729	0.0970	0.0666
Methyl butyrate	0.0	0.2422	0.0640	0.0438
" "	92.1	0.4308	0.1139	0.0809
Ethyl "	0.0	0.2238	0.0573	0.0406
" "	96.5	0.4112	0.1064	0.0756
" valerate	0.0	0.2050	0.0505	0.0366
" "	97.6	0.3784	0.0932	0.0676
Ether	0.0	0.2960	0.0775	0.0552
"	19.9	0.3410	0.0893	0.0636
Water	0.0	0.6870	0.1980	0.1310
"	49.5	1.0000	0.2827	0.1811
"	92.4	1.1794	0.3451	0.2384

* Taken from Winkelmann's papers (Wied. Ann. vols. 22, 23, and 26). The coefficients for 0° were calculated by Winkelmann on the assumption that the rate of diffusion is proportional to the absolute temperature. According to the investigations of Loschmidt and of Obermeyer the coefficient of diffusion of a gas, or vapor, at 0° C and a pressure of 76 centimetres of mercury may be calculated from the observed coefficient at another temperature and pressure by the formula $k_0 = k_T\left(\frac{T_0}{T}\right)^n \frac{76}{p}$, where T is temperature absolute and p the pressure of the gas. The exponent n is found to be about 1.75 for the permanent gases and about 2 for condensible gases. The following are examples: Air — CO_2, $n = 1.968$; CO_2 — N_2O, $n = 2.05$; CO_2 — H, $n = 1.742$; CO — O, $n = 1.785$. H — O, $n = 1.755$; O — N, $n = 1.792$. Winkelmann's results, as given in the above table, seem to give about 2 for vapors diffusing into air, hydrogen or carbon dioxide.

DIFFUSION OF GASES, VAPORS AND METALS

TABLE 185.—Coefficients of Diffusion for Various Gases and Vapors *

Gas or Vapor diffusing.	Gas or Vapor diffused into.	Temp. °C.	Coefficient of Diffusion.	Authority.
Air	Hydrogen	0	0.661	Schulze.
"	Oxygen	0	0.1775	Obermayer.
Carbon dioxide	Air	0	0.1423	Loschmidt.
" "	"	0	0.1360	Waitz.
" "	Carbon monoxide	0	0.1405	Loschmidt.
" "	" "	0	0.1314	Obermayer.
" "	Hydrogen	0	0.5437	"
" "	Methane	0	0.1465	"
" "	Nitrous oxide	0	0.0983	Loschmidt.
" "	Oxygen	0	0.1802	"
Carbon disulphide	Air	0	0.0995	Stefan
Carbon monoxide	Carbon dioxide	0	0.1314	Obermayer.
" "	Ethylene	0	0.101	"
" "	Hydrogen	0	0.6422	Loschmidt.
" "	Oxygen	0	0.1802	"
" "	"	0	0.1872	Obermayer.
Ether	Air	0	0.0827	Stefan.
"	Hydrogen	0	0.3054	"
Hydrogen	Air	0	0.6340	Obermayer.
"	Carbon dioxide	0	0.5384	"
"	" monoxide	0	0.6488	"
"	Ethane	0	0.4593	"
"	Ethylene	0	0.4863	"
"	Methane	0	0.6254	"
"	Nitrous oxide	0	0.5347	"
"	Oxygen	0	0.6788	"
Nitrogen	"	0	0.1787	"
Oxygen	Carbon dioxide	0	0.1357	"
"	Hydrogen	0	0.7217	Loschmidt.
"	Nitrogen	0	0.1710	Obermayer.
Sulphur dioxide	Hydrogen	0	0.4828	Loschmidt.
Water	Air	8	0.2390	Guglilemo.
"	"	18	0.2475	"
"	Hydrogen	18	0.8710	"

* Compiled for the most part from a similar table in Landolt & Börnstein's Phys. Chem. Tab.

TABLE 186.— Diffusion of Metals into Metals

$\frac{dv}{dt} = k\frac{d^2v}{dx^2}$; where x is the distance in direction of diffusion; v, the degree of concentration of the diffusing metal; t, the time; k, the diffusion constant = the quantity of metal in grams diffusing through a sq. cm in a day when unit difference of concentration (gr. per cu. cm) is maintained between two sides of a layer one cm thick.

Diffusing Metal.	Dissolving Metal	Temperature °C.	k	Diffusing Metal.	Dissolving Metal.	Temperature °C.	k.
Gold	Lead	555	3.19	Platinum	Lead	492	1.69
"	"	492	3.00	Lead	Tin	555	3.18
"	"	251	0.03	Rhodium	Lead	550	3.04
"	"	200	0.008	Tin	Mercury	15	1.22*
"	"	165	0.004	Lead	"	15	1.0*
"	"	100	0.00002	Zinc	"	15	1.0*
"	Bismuth	555	4.52	Sodium	"	15	0.45*
"	Tin	555	4.65	Potassium	"	15	0.40*
Silver	"	555	4.14	Gold	"	15	0.72*

From Roberts-Austen, Philosophical Transactions, 187A, p. 383, 1896.
* These values are from Guthrie.

TABLE 187

SOLUBILITY OF INORGANIC SALTS IN WATER (TEMPERATURE VARIATION)

The numbers give the number of grams of the *anhydrous* salt soluble in 1000 grams of water at the given temperatures.

Salt.	Temperature Centigrade.										
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
$AgNO_3$	1150	1600	2150	2700	3350	4000	4700	5500	6500	7600	9100
$Al_2(SO_4)_3$	313	335	362	404	457	521	591	662	731	808	891
$Al_2K_2(SO_4)_4$	30	–	–	84	–	–	248	–	–	–	1540
$Al_2(NH_4)_2(SO_4)_4$	26	45	66	91	124	159	211	270	352	–	–
B_2O_3	11	15	22	–	40	–	62	–	95	–	157
$BaCl_2$	316	333	357	382	408	436	464	494	524	556	588
$Ba(NO_3)_2$	50	70	92	116	142	171	203	236	270	306	342
$CaCl_2$	595	650	745	1010	1153	–	1368	1417	1470	1527	1590
$CoCl_2$	405	450	500	565	650	935	940	950	960	–	1030
$CsCl$	1614	1747	1865	1973	2080	2185	2290	2395	2500	2601	2705
$CsNO_3$	93	149	230	339	472	644	838	1070	1340	1630	1970
Cs_2SO_4	1671	1731	1787	1841	1899	1949	1999	2050	2103	2149	2203
$Cu(NO_3)_2$	818	–	1250	–	1598	–	1791	–	2078	–	–
$CuSO_4$	149	–	–	255	295	336	390	457	535	627	735
$FeCl_2$	–	–	685	–	–	820	–	–	1040	1050	1060
Fe_2Cl_6	744	819	918	–	–	3151	–	–	5258	–	5357
$FeSO_4$	156	208	264	330	402	486	550	560	506	430	–
$HgCl_2$	43	66	74	84	96	113	139	173	243	371	540
KBr	540	–	650	–	760	–	860	–	955	–	1050
K_2CO_3	1050	–	–	1140	1170	1210	1270	1330	1400	1470	1560
KCl	285	312	343	373	401	429	455	483	510	538	566
$KClO_3$	33	50	71	101	145	197	260	325	396	475	560
K_2CrO_4	589	609	629	650	670	690	710	730	751	771	791
$K_2Cr_2O_7$	50	85	131	–	292	–	505	–	730	–	1020
$KHCO_3$	225	277	332	390	453	522	600	–	–	–	–
KI	1279	1361	1442	1523	1600	1680	1760	1840	1920	2010	2090
KNO_3	133	209	316	458	639	855	1099	1380	1690	2040	2460
KOH	970	1030	1120	1260	1360	1400	1460	1510	1590	1680	1780
K_2PtCl_6	7	9	11	14	18	22	26	32	38	45	52
K_2SO_4	74	92	111	130	148	165	182	198	214	228	241
$LiOH$	127	127	128	129	130	133	138	144	153	–	175
$MgCl_2$	528	535	545	–	575	–	610	–	660	–	730
$MgSO_4$ (7aq)	260	309	356	409	456	–	–	–	–	–	–
" (6aq)	408	422	439	453	–	504	550	596	642	689	738
NH_4Cl	297	333	372	414	458	504	552	602	656	713	773
NH_4HCO_3	119	159	210	270	–	–	–	–	–	–	–
NH_4NO_3	1183	–	–	2418	2970	3540?	4300?	5130?	5800	7400	8710
$(NH_4)_2SO_4$	706	730	754	780	810	844	880	916	953	992	1033
$NaBr$	795	845	903	–	1058	1160	1170	–	1185	–	1205
$Na_2B_4O_7$	–	16	–	39	–	105	200	244	314	408	523
Na_2CO_3 (10aq)	71	126	214	409	–	–	–	–	–	–	–
" (7aq)	204	263	335	435	(1aq)	475	464	458	452	452	452
$NaCl$	356	357	358	360	363	367	371	375	380	385	391
$NaClO_3$	820	890	990	–	1235	–	1470	–	1750	–	2040
Na_2CrO_4	317	502	900	–	960	1050	1150	–	1240	–	1260
$Na_2Cr_2O_7$	1630	1700	1800	1970	2200	2480	2830	3230	3860	–	4330
$NaHCO_3$	69	82	96	111	127	145	164	–	–	–	–
Na_2HPO_4	25	39	93	241	639	–	–	949	–	–	988
NaI	1590	1690	1790	1900	2050	2280	2570	–	2950	–	3020
$NaNO_3$	730	805	880	962	1049	1140	1246	1360	1480	1610	1755

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

TABLE 187 (*continued*).—Solubility of Inorganic Salts in Water (Temperature Variation)

The numbers give the number of grams of the *anhydrous* salt soluble in 1000 grams of water at the given temperatures.

Salt.	Temperature Centigrade.										
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
$NaOH$	420	515	1090	1190	1290	1450	1740	–	3130	–	–
$Na_4P_2O_7$	32	39	62	99	135	174	220	255	300	–	–
Na_2SO_3	141	–	287	–	495	–	–	–	–	–	330
Na_2SO_4 (10aq)	50	90	194	400	482	468	455	445	437	429	427
" (7aq)	196	305	447	–							
$Na_2S_2O_3$	525	610	700	847	1026	1697	2067	–	2488	2542	2660
$NiCl_2$	–	600	640	680	720	760	810	–	–	–	–
$NiSO_4$	272	–	–	425	–	502	548	594	632	688	776
$PbBr_2$	5	6	8	12	15	20	24	28	33	–	48
$Pb(NO_3)_2$	365	444	523	607	694	787	880	977	1076	1174	1270
$RbCl$	770	844	911	976	1035	1093	1155	1214	1272	1331	1389
$RbNO_3$	195	330	533	813	1167	1556	2000	2510	3090	3750	4520
Rb_2SO_4	364	426	482	535	585	631	674	714	750	787	818
$SrCl_2$	442	483	539	600	667	744	831	896	924	962	1019
SnI_2	–	–	10	12	14	17	21	25	30	34	40
$Sr(NO_3)_2$	395	549	708	876	913	926	940	956	972	990	1011
$Th(SO_4)_2$ (9aq)	7	10	14	20	30	51	–	–	–	–	–
" (4aq)	–	–	–	–	40	25	16	11	–	–	–
$TlCl$	2	2	3	5	6	8	10	13	16	20	–
$TlNO_3$	39	62	96	143	209	304	462	695	1110	2000	4140
Tl_2SO_4	27	37	49	62	76	92	109	127	146	165	–
$Yb_2(SO_4)_3$	442	–	–	–	–	–	104	72	69	58	47
$Zn(NO_3)_2$	948	–	–	–	2069	–	–	–	–	–	–
$ZnSO_4$	–	–	–	–	700	768	–	890	860	920	785

TABLE 188.—Solubility of a Few Organic Salts in Water (Temperature Variation)

Salt.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
$H_2(CO_2)_2$	36	53	102	159	228	321	445	635	978	1200	–
$H_2(CH_2.CO_2)_2$	28	45	69	106	162	244	358	511	708	–	1209
Tartaric acid	1150	1260	1390	1560	1760	1950	2180	2440	2730	3070	3430
Racemic "	92	140	206	291	433	595	783	999	1250	1530	1850
$K(HCO_2)$	2900	–	3350	–	3810	–	4550	–	5750	–	7900
$KH(C_4H_4O_6)$	3	4	6	9	13	18	24	32	45	57	69

TABLE 189.—Solubility of Gases in Water (Temperature Variation)

The table gives the weight in grams of the gas which will be absorbed in 1000 grams of water when the partial pressure of the gas plus the vapor pressure of the liquid at the given temperature equals 760 mm.

Gas.	0°	10°	20°	30°	40°	50°	60°	70°	80°
O_2	.0705	.0551	.0443	.0368	.0311	.0263	.0221	.0181	.0135
H_2	.00192	.00174	.00160	.00147	.00138	.00129	.00118	.00102	.00079
N_2	.0293	.0230	.0189	.0161	.0139	.0121	.0105	.0089	.0069
Br_2	431.	248.	148.	94.	62.	40.	28.	18.	11.
Cl_2	–	9.97	7.29	5.72	4.59	3.93	3.30	2.79	2.23
CO_2	3.35	2.32	1.69	1.26	0.97	0.76	0.58	–	–
H_2S	7.10	5.30	3.98	–	–	–	–	–	–
NH_3	987.	689.	535.	422.	–	–	–	–	–
SO_2	228.	162.	113.	78.	54.	–	–	–	–

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

Table 190.—Change of Solubility Produced by Uniform Pressure*

Pressure in atmospheres.	$CdSO_4 8/3H_2O$ at 25°		$ZnSO_4 \cdot 7H_2O$ at 25°		Mannite at 24.05°		NaCl at 24.05°	
	Conc. of satd. soln. gs. $CdSO_4$ per 100 gs. H_2O.	Percentage change.	Conc. of satd. soln. gs. $ZnSO_4$ per 100 gs. H_2O.	Percentage change.	Conc. of satd. soln. gs. mannite per 100 gs. H_2O.	Percentage change.	Conc. of satd. soln. gs. NaCl per 100 gs. H_2O.	Percentage change.
1	76.80	—	57.95	—	20.66	—	35.90	—
500	78.01	+ 1.57	57.87	— 0.14	21.14	+ 2.32	36.55	+ 1.81
1000	78.84	+ 2.68	57.65	— 0.52	21.40	+ 3.57	37.02	+ 3.12
1500	—	—	—	—	21.64	+ 4.72	37.36	+ 4.07

* E. Cohen and L. R. Sinnige, *Z. physik. Chem* 67, p. 432, 1909; 69, p 102, 1909. E. Cohen, K. Inouye and C. Euwen, *ibid.* 75, p. 257, 1911. These authors give a critical résumé of earlier work along this line.

Table 191.—Commonly Used Organic Solvents

Arranged in the order of their Boiling Points

(Table by Dr. J. W. H. Randall, reprinted with permission of Chemical Catalog Co.)

Name	Boiling point °C	Name	Boiling point °C
Ethyl ether	34.54	Xylene (o)	144
Carbon disulphide	46.25	Amyl acetate	147.6
Acetone	56.08	Cellosolve acetate	153
Methyl acetate	57.1	Ethyl lactate	154
Chloroform	61.2	Cyclohexanone	156.7
Methyl alcohol	64.5	Furfural	158–162
Carbon tetrachloride	76.74	Butyl cellosolve	170.6
Ethyl acetate	77.15	Ethyl acetoacetate	180.0
Ethyl alcohol	78.32	Diethyl oxalate	186.1
Benzol	79.6	Ethylene glycol	197.2
Isopropyl alcohol	82.26	Carbitol	198
Ethylene dichloride	83.5	Benzyl alcohol	205.8
Trichlorethylene	88	Ethyl benzoate	213.2
Ethyl propionate	99.1	Butyl stearate	223 (25mm)
Toluene	110.7	Butyl carbitol	222
Butyl alcohol (n)	117.7	Diethylene glycol	245
Ethyl butyrate	121.3	Triphenyl phosphate	245 (11mm)
Methyl cellosolve	124.5	Triacetin	259
Diethyl carbonate	125.8	Diacetin	261
Butyl acetate	126.5	Dimethyl phthalate	282
Tetrachlorethane	130	Diethyl phthalate	296
Cellosolve	134.8	Dibutyl phthalate	340
Ethyl benzene	136.1	Diamyl phthalate	344
Amyl alcohol (n)	137.9		

For producers of solvents, see the following pages of Chemical Engineering Catalog:
1017, 1018, 1020, 1023, 1024, 1027, 1028–9, 1030, 1031, 1032, 1033, 1036–7, 1038, 1039, 1041, 1043, 1046–7, 1048, 1050, 1052, 1056, 1060, 1063, 1066, 1068–9, 1072–3, 1077, 1078, 1082–3, 1084, 1087, 1091, 1094, 1095.

ABSORPTION OF GASES BY LIQUIDS *

Temperature Centigrade. t	Absorption Coefficients, a_t, for Gases in Water						
	Carbon dioxide. CO_2	Carbon monoxide. CO	Hydrogen. H	Nitrogen. N	Nitric oxide. NO	Nitrous oxide. N_2O	Oxygen. O
0	1.797	0.0354	0.02110	0.02399	0.0738	1.048	0.04925
5	1.450	.0315	.02022	.02134	.0646	0.8778	.04335
10	1.185	.0282	.01944	.01918	.0571	0.7377	.03852
15	1.002	.0254	.01875	.01742	.0515	0.6294	.03456
20	0.901	.0232	.01809	.01599	.0471	0.5443	.03137
25	0.772	.0214	.01745	.01481	.0432	–	.02874
30	–	.0200	.01690	.01370	.0400	–	.02646
40	0.506	.0177	.01644	.01195	.0351	–	.02316
50	–	.0161	.01608	.01074	.0315	–	.02080
100	0.244	.0141	.01600	.01011	.0263	–	.01690

Temperature Centigrade. t	Air.	Ammonia. NH_3	Chlorine. Cl	Ethylene. C_2H_4	Methane. CH_4	Hydrogen sulphide. H_2S	Sulphur dioxide. SO_2
0	0.02471	1174.6	3.036	0.2563	0.05473	4.371	79.79
5	.02179	971.5	2.808	.2153	.04889	3.965	67.48
10	.01953	840.2	2.585	.1837	.04367	3.586	56.65
15	.01795	756.0	2.388	.1615	.03903	3.233	47.28
20	.01704	683.1	2.156	.1488	.03499	2.905	39.37
25	–	610.8	1.950	–	.02542	2.604	32.79

Temperature Centigrade. t	Absorption Coefficients, a_t, for Gases in Alcohol, C_2H_5OH								
	Carbon dioxide. CO_2	Ethylene. C_2H_4	Methane. CH_4	Hydrogen. H	Nitrogen. N	Nitric oxide. NO	Nitrous oxide. N_2O	Hydrogen sulphide. H_2S	Sulphur dioxide. SO_2
0	4.329	3.595	0.5226	0.0692	0.1263	0.3161	4.190	17.89	328.6
5	3.891	3.323	.5086	.0685	.1241	.2998	3.838	14.78	251.7
10	3.514	3.086	.4953	.0679	.1228	.2861	3.525	11.99	190.3
15	3.199	2.882	.4828	.0673	.1214	.2748	3.215	9.54	144.5
20	2.946	2.713	.4710	.0667	.1204	.2659	3.015	7.41	114.5
25	2.756	2.578	.4598	.0662	.1196	.2595	2.819	5.62	99.8

* This table contains the volumes of different gases, supposed measured at 0° C and 76 centimeters' pressure, which unit volume of the liquid named will absorb at atmospheric pressure and the temperature stated in the first column. The numbers tabulated are commonly called the absorption coefficients for the gases in water, or in alcohol, at the temperature t and under one atmosphere of pressure. The table has been compiled from data published by Bohr & Bock, Bunsen, Carius, Dittmar, Hamberg, Henrick, Pagliano & Emo, Raoult, Schönfeld, Setschenow, and Winkler. The numbers are in many cases averages from several of these authorities.

NOTE. — The effect of increase of pressure is generally to increase the absorption coefficient. The following is approximately the magnitude of the effect in the case of ammonia in alcohol at a temperature of 23° C:

$$\begin{cases} P = 45 \text{ cms} & 50 \text{ cms} & 55 \text{ cms} & 60 \text{ cms} & 65 \text{ cms} \\ a_{23} = 69 & 74 & 79 & 84 & 88 \end{cases}$$

According to Setschenow the effect of varying the pressure from 45 to 85 centimeters in the case of carbonic acid in water is very small.

CAPILLARITY AND SURFACE TENSION OF LIQUIDS

Table 193.—Water and Alcohol in Contact with Moist Air

Values represent means. See I.C.T. and L. and B. for more elaborate tables. Tension (γ) in dynes/cm.

°C	H_2O	C_2H_5OH	°C	H_2O	C_2H_5OH	°C	H_2O
−5	76.4		35	70.3	21.0	75	64.3
0	75.6	24.0	40	69.5	20.6	80	62.5
5	74.8	23.5	45	68.7	20.2	85	61.6
10	74.2	23.1	50	67.9	19.8	90	60.7
15	73.4	22.7	55	67.0	19.4	95	59.8
20	72.7	22.3	60	66.1	19.0	100	58.8
25	71.9	21.8	65	67.0	18.6	...	...
30	71.1	21.4	70	64.3	18.2	...	...

Table 194.—Miscellaneous Liquids in Contact with Air

Liquid	°C	γ Dynes per cm	
Aceton, $(CH_3)_2CO$....	20	23.7	
Acetic acid, CH_3CO_2H.	20	27.6	
Amyl alcohol, $C_5H_{12}O$.	20	24	
Aniline, C_6H_7N.......	20	43	
Benzene, C_6H_6.......	0	27	Richards '21
"	20	28.9	Sudgen '24
Bromoform, $CHBr_3$...	20	41.5	Mean
Butyric acid.........	15	26.7	$CH_3(CH_2)_2CO_2H$
Carbon disulphide....	20	32.3	CS_2
Carbon tetrachloride..	20	26.8	CCl_4
Chloroform, $CHCl_3$...	20	27.2	Mean
Ether, $C_4H_{10}O$........	20	17.01	
Ethyl chloride.......	20	16.2	CH_3Cl
Glycerine............	18	63	$C_3H_5(OH)_3$
Methyl alcohol.......	20	22.6	CH_3OH
Olive oil.............	18	33.1	
Petroleum...........	25	26	
Phenol, C_6H_6O.......	20	41.0	
Propyl alcohol.......	20	23	$CH_3(CH_2)_1OH$
Silicon tetrachloride, $SiCl_4$..............	19	17.0	Ramsay '93
Toluene, C_7H_8........	20	28.4	
Turpentine..........	20	27	

Table 195.—Solutions of Salts in Water

Salt	% Salt	°C	Dynes cm
$BaCl_2$....	0	30	71.1
	24.6	30	75.6
$CaCl_2$....	0	30	71.1
	12.3	30	75.7
	31.9	30	86.4
HCl......	0	20	73.0
	15	20	72.0
	25	20	70.7
KCl......	0	30	71.1
	23.3	30	76.8
	21.1	18	77.7
NaCl.....	0	18	72.4
	7.6	18	74.8
	13.7	18	76.9
NH_4Cl...	0	18	72.5
	11	18	74.9
K_2CO_3....	0	30	71.1
	39.4	30	89.4
	53.6	30	107.2
Na_2CO_3...	0	30	71.1
	10.5	30	73.9
	24.4	30	76.5
	63.1	30	80.6
KNO_3....	0	18	72.6
	15.2	18	74.5
	21.5	18	75.4
$NaNO_3$...	0	30	71.1
	35.6	30	78.4
	50.9	30	82.8
$CuSO_4$....	0	30	71.1
	25.4	30	74.1
H_2SO_4....	0	18	72.8
	12.7	18	73.5
	47.6	18	76.7
	80.3	18	71.2
	90	18	63.6
K_2SO_4....	0	18	72.7
	9.1	18	74.6
HNO_3....	7.2	20	73.1
	50	20	65.4
	70	20	59.4
NaOH...	0	20	72.8
	10	20	77.3
	20	20	85.8
	30	20	95.1
KOH....	0	18	72.8
	3.8	18	74.1
	7.8	18	75.5

TABLE 196.—Surface Tension of Liquids *

Liquid.	Specific gravity.	Surface tension in dynes per centimeter of liquid in contact with — Air.	Water.	Mercury.
Water	1.0	75.0	0.0	(392)
Mercury	13.543	513.0	392.0	0
Bisulphide of carbon	1.2687	30.5	41.7	(387)
Chloroform	1.4878	(31.8)	26.8	(415)
Ethyl alcohol	0.7906	(24.1)	–	364
Olive oil	0.9136	34.6	18.6	317
Turpentine	0.8867	28.8	11.5	241
Petroleum	.7977	29.7	(28.9)	271
Hydrochloric acid	1.10	(72.9)	–	(392)
Hyposulphite of soda solution	1.1248	69.9	–	429

TABLE 197.—Surface Tension of Liquids at Solidifying Point †

Substance.	Temperature of solidification. Cent.°	Surface tension in dynes per centimeter.	Substance.	Temperature of solidification. Cent.°	Surface tension in dynes per centimeter.
Platinum	2000	1691	Antimony	432	249
Gold	1200	1003	Borax	1000	216
Zinc	360	877	Carbonate of soda	1000	210
Tin	230	599	Chloride of sodium	–	116
Mercury	—40	588	Water	0	87.9‡
Lead	330	457	Selenium	217	71.8
Silver	1000	427	Sulphur	111	42.1
Bismuth	265	1390	Phosphorus	43	42.0
Potassium	58	371	Wax	68	34.1
Sodium	90	258			

* This table of tensions at the surface separating the liquid named in the first column and air, water or mercury as stated at the head of the last three columns, is from Quincke's experiments (Pogg. Ann. vol. 139, and Phil. Mag. 1871). The numbers given are the equivalent in dynes per centimeter of those obtained by Worthington from Quincke's results (Phil. Mag. vol. 20, 1885) with the exception of those in brackets, which were not corrected by Worthington; they are probably somewhat too high, for the reason stated by Worthington. The temperature was about 20° C.

† Quincke, "Pogg. Ann." vol. 135, p. 661.

‡ It will be observed that the value here given on the authority of Quincke is much higher than his subsequent measurements, as quoted above, give.

‖ "Proc. Roy. Soc." 1877, and "Phil. Trans. Roy. Soc." 1881, 1883, and 1893.

NOTE. — Quincke points out that substances may be divided into groups in each of which the ratio of the surface tension to the density is nearly constant. Thus, if this ratio for mercury be taken as unit, the ratio for the bromides and iodides is about a half: that of the nitrates, chlorides, sugars, and fats, as well as the metals, lead, bismuth, and antimony, about 1; that of water, the carbonates, sulphates, and probably phosphates, and the metals platinum, gold, silver, cadmium, tin, and copper, 2; that of zinc, iron, and palladium, 3; and that of sodium, 6.

TABLE 198.—Vapor Pressure and Rate of Evaporation

°K.	Mo mm	W mm	Evaporation rate. g/cm²/sec. Mo	W	Platinum. °K.	mm	g/cm²/sec.
1800	$0.0_{8}643$	—	$0.0_{10}863$	—	1000	$0.0_{17}324$	$0.0_{19}832$
2000	$0.0_{6}789$	$0.0_{11}645$	$0.0_{7}100$	$0.0_{12}114$	1200	$0.0_{12}111$	$0.0_{14}260$
2200	$0.0_{4}396$	$0.0_{9}849$	$0.0_{6}480$	$0.0_{10}144$	1400	$0.0_{9}188$	$0.0_{11}401$
2400	$0.0_{2}1027$	$0.0_{7}492$	$0.0_{4}120$	$0.0_{9}798$	1600	$0.0_{7}484$	$0.0_{9}966$
2600	0.0160	$0.0_{5}151$	$0.0_{3}179$	$0.0_{7}236$	1800	$0.0_{5}350$	$0.0_{7}667$
2800	0.1679	$0.0_{4}286$	$0.0_{2}181$	$0.0_{6}429$	2000	$0.0_{3}107$	$0.0_{5}195$
3000	—	$0.0_{3}362$	—	$0.0_{5}523$	4180	760 mm	—
3200	3890° }	$0.0_{2}333$	—	$0.0_{4}467$	Langmuir, MacKay, Phys. Rev. 2, 1913; 4, 1914.		
3500	760 mm }	0.0572	—	$0.0_{3}769$	Order of vacuum, 0.001 mm.		

$p = K.T^{-\frac{1}{2}}e^{-\lambda_0/RT}$ dynes/cm². Egerton, Phil. Mag. 33, p. 33, 1917.

Zn, $\lambda_0 = 3.28 \times 10^4$; $K = 1.17 \times 10^{14}$ Cd, $\lambda_0 = 2.77 \times 10^4$; $K = 5.27 \times 10^{13}$

Hg, $\lambda_0 = 1.60 \times 10^4$; $= 3.72 \times 10^{13}$ (Knudsen)

TABLE 199
VAPOR PRESSURE OF ELEMENTS

(Over liquid unless otherwise noted)

Hydrogen °K.	mm	Helium °K.	mm	Neon °K.	atm.	Argon °K.	mm	Krypton °K.	mm	Xenon °K.	mm
20.48	787	5.16	16680	41.38	17.43	90.35	1026	210.5	41240	287.7	44110
20.36	760	4.9	1329	36.27	7.97	87.31	746	201.5	31620	255.6	21970
19.65	611	4.20	758	31.32	2.98	83.93	512	170.9	11970	244.2	15870
18.03	552	3.52	360	27.17	1.00	77.48	201	112.7	387	231.4	11130
16.49	192	1.48	4.2	*20.4*	*12.8* mm	69.43	48.0	88.6	17.4	237.4	13500
14.10	59.5	...	......	*15.6*	*2.4*	65.49	22.0	84.2	9	183.2	2020
Onnes, 1923		Onnes, 1915-6		Onnes, 1917 Travers, 1902		Born, 1922		Ramsay, Travers, 1901			

Niton °K.	mm	Oxygen °K.	mm	Nitrogen °K.	mm	Chlorine °C	atm.	Bromine °C	mm	Iodine °C	mm
377.5	62	62.37	9.59	77.33	760	+100	41.7	+58.75	760	+55	3.084
364.4	53	68.57	36.1	76.65	700	+ 20	6.62	51.95	600	50	2.154
321.7	26.4	71.71	64	74.03	500	0	3.66	40.45	400	45	1.498
290.3	13.2	77.59	162.2	72.39	400	− 33.6	760	23.45	200	40	1.025
262.8	6.6	86.18	493	70.42	300	− 50	350	8.20	100	35	.699
212.4	1.05	90.13	760	67.80	200	− 70	118	− 7.0	45	30	.469
202.6	.66	90.47	786.6	63.65	100	− 80	62	−12.0	30	15	.131
						− 88	37	−16.65	20	0	.030
Gray, Ramsay, 1909		Cath, 1908		Fischer, Alt., 1902		Knietsch, 1890		Ramsay, Young, 1886		Baxter, Hickey, Holmes, 1907	

Ozone °K.	mm	Arsenic, solid °C	atm.	Bismuth °C	atm.	Cadmium °C	mm	Calcium °C	mm	Caesium °C	mm
120	34	500	.076	2060	16.5	793	1000	982	6	247	.30
162	760	616	1.00	1950	11.7	751	371	1028	23	276	1.00
89.94	.089	697	4.85	1740	6.3	571	.52	1049	41	316	3.02
86.01	.042	790	22.3	1420	1.0	350	.279	1085	99	353	6.68
83.24	.0152			1310	.338	262	.013	1129	287	397	15.9
81.36	.0068			1200	.134			1175	760	670	760
Spangenburg, 1926 Reisenfeld		Horiba, 1923		Greenwood, 1910		Braune, 1920		Ruff, Hartmann, 1914		Mears, 1913	

Copper °C	mm	Gallium °C	mm	Gold °C	mm	Lead °C	mm	Lead °C	mm	Magnesium °C	mm
1875	20	926	.0004	1155	.00007	808	.08	1315	105	623	9
1980	100	1009	.003	1985	17	996	1.75	1410	266	742	20
2180	257	1125	.023	2315	130	1178	16.8	1325	760	986	211
2310	760			2500	400	1275	73	1870	6 atm.	1080	751
Greenwood, 1911		Harteck, 1927		Harteck, Ruff		Wartenberg, 1913		Greenwood, 1911		Ruff, Hartmann, 1924	

Niton °C	mm	Potassium °C	mm	Rubidium °C	mm	Silicon °C	mm	Silver °C	mm
−70.6	.66	406.2	4.6	91	.00006	1890	10	1038	.011
−60.8	1.05	469.1	16.2	115	.0004	2085	110	1368	.82
+17.1	13.2	528.5	44.8	250	.98	2195	210	1660	103
+91.2	52.8	759.8	783	366	5.82	2442	760	1758	200
Gray, Ramsay, 1909		Flock, Rodebush, 1926		various		Ruff, Konschak, 1926		various	

TABLE 200

VAPOR PRESSURE OF ORGANIC LIQUIDS

The vapor pressures on this page are in millimeters over a liquid phase unless distinguished by the subscript $_s$. They are generally means from various determinations.

°C	Acetone C_3H_6O	Benzine C_6H_6	Camphor $C_{10}H_{16}O$	Carbon bisulphide CS_2	Carbon tetrachloride CCl_4	Chloroform $CHCl_3$	Ethane C_2H_6	Ethyl ether $C_4H_{10}O$	Ethyl bromide C_2H_5Br	Turpentine $C_{10}H_6$
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
−90	.02	...	...	...	−70°	−60°	−100°	−101.3°	...	...
−57	1.26	−50°, .3	...	−80°	.14	.8	390	.058	...	...
−40	...	...	...	.6	−50°	4.8	− 90°	− 60°	...	...
−30	...	.3	...	−25°	.92	10	700	4	...	...
−20	...	...	...	.34	...	19	− 80°	− 40°	59	...
−10	...	14	...	80	...	...	1180	19	102	...
0	...	26.5	.06	127	33	610	− 75°	186.1	166	.2
+ 5	...	34	...	160	43	...	1500	...	207	...
10	116	45	.10	198	56	100	...	291.8	257	.3
15	...	59	...	244	71	...	...	...	317	...
20	185	75	.15	298	90	160	...	442.4	386	.4
30	283	119	.26	433	141	247	...	648	564	.7
40	422	182	.60	617	213	370	...	921	802	1.1
50	612	269	1.30	855	315	540	...	1276	1113	1.7
60	860	390	2.6	1170	448	750	...	1728	1510	2.6
70	1190	548	4.6	1570	620	1025	...	2294	2015	4.1
80	1860	750	9.2	2040	843	1400	...	2991	2640	6.1
90	2140	1010	...	2620	1120	2130	...	3840	3400	9.0
100	2800	1340	26	3000	1460	2420	...	4860	4310	13.1
110	3590	1740	...	4160	1880	...	...	...	5390	18.6
120	4550	2200	...	5150	2390	3900	...	7500	6660	25.7
130	5670	2800	...	...	3000	4900	...	...	8120	34.9
140	6970	3500	...	...	3700	6000	...	11080	9780	...
150	...	4300	170	9100	4500	7300	...	160° 15800	...	...
200	...	...	...	...	10900	...	...	180° 21800	...	...

Ethylene C_2H_4		Glycerine C_3H_8O		Methane CH_4		Methyl ether $(CH_3)_2O$		Naphthalene $C_{10}H_8$		Ethyl chloride C_2H_5Cl	
°C	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm
−150	14.9	118	.24	−180	119	− 67	78	0	.02$_s$	−30	110
−190	45.6	161	6.5	−175	212	− 60	120	20	.06$_s$	−20	188
−145	26.7	175	13	−170	353	− 41.4	326	50	.81$_s$	−10	302
−135	74.4	190	32	−165	559	− 30.9	524	70	4.0$_s$	0	465
−130	117.2	220	100	−160	848	−241	782	80	10	10	691
−120	260	260	385	−155	1229	*0*	*2.52* atm.	90	13	20	1000
−110	519			−150	1720	*254*	*6.05* "	100	20	30	1400
−103	792					*49.75*	*11.2* "	110	29	50	2580
						80.1	*22.1* "	120	43	75	4980
						99.9	*32.1* "	150	119	100	8720
						125.9	51 "	200	490		

Table 200 (continued).—Vapor Pressure of Organic Liquids

°C	Ammonia NH_3	Carbon dioxide CO_2	Ethyl iodide C_2H_5I	Ethyl acetate	Hydrogen sulphide H_2S	Methyl chloride CH_3Cl	Napthalin $C_{10}H_8$	Sulphur dioxide SO_2	Toluol $C_{10}H_8$	
	atm.	atm.	mm	mm	mm	mm	mm	mm	°C	mm
−50	.403	6.74	...	...	1216	...	...	86	−91.9	.002
−30	1.180	14.10	...	...	2840	579	...	286	−81.7	.005
−25	1.496	16.61	...	...	...	718	...	379	−77.4	.007
−20	1.877	19.44	...	6.5	4100	883	...	474	−67.5	.020
−15	2.332	22.60	...	...	...	1079	...	...	−57.7	.060
−10	2.870	26.13	...	12.9	5720	1310	...	760	−38.0	.39
− 5	3.502	30.05	...	...	...	1579	...	...	−24.2	1.47
0	4.238	34.38	41.5	24.3	7750	1891	...	1155	− 2.9	5.72
+ 5	5.090	39.16	53.5	...	...	2250	...	...	0	6.86
10	6.068	44.41	68.6	42.7	10300	2660	...	1714	+15.0	16.8
15	7.188	50.17	...	...	...	3134	...	...	+25.8	28.7
20	8.458	56.50	108.5	72.8	14000	3667	...	2460	...	...
25	9.896	63.45	...	...	...	4267	...	...	...	...
30	11.512	71.4	167.6	119	17500	4940	...	3420	...	...
35	13.321	...	...	...	...	5700	...	...	...	...
40	15.339	(I.C.T.	250	186	22000	6650	...	4650	Drucker,	
45	17.580	1928)	...	...	...	...	...	...	Jumen,	
50	20.060	...	362	282	27500	8510	...	6210	1915	
60	25.80	...	510	415	...	10900	...	8150	Barker,	
70	32.69	...	...	596	40400	14300	...	10540	1910	
80	40.90	...	...	833	...	16800	9.6	...		
90	50.56	...	...	1130	...	21000	13.0	...		
100	61.82	...	...	1515	...	25800	19.7	*27.8* atm.		
	Cragoe 1920			{200° 15600		{141° 53600	{200° 490	{150° *71.4* "		

Table 201.—Vapor Pressure at Low Temperatures

Many of the following values are extrapolations made by Langmuir by means of plots of log p against 1/T. Gen. Elec. Rev. 23, 681, 1920. 1 bar = 0.000000987 atm. = 0.000750 mm Hg.

Gas	°C	Mm	Gas	°C	Bars
O_2	−182.9	760	CO_2	−148	100
	−211.2	7.75		−168	1
N_2	−195.8	760		−182	.01
	−210.5	86		−193	.0001
CO	−190	863	Ice	− 60	9.6
	−200	249		− 75	1.0
CH_4	−185.8	79.8		− 89	.1
	−201.5	50.2		−100	.01
A	−186.2	760		−110	.001
	−194.2	300	Hg	+ 30	3.7
C_2H_4	−175.7	.76		+ 20	1.6
	−188	.076		+ 10	.65
	−197	.0076		0	.25
	−205	.00076		− 10	.087
C_2H_6	−150	7.6		− 20	.029
	−180	.076		− 40	.0023
	−190	.0076		− 78	4.3×10^{-6}
	−198	.00076		−180	2.3×10^{-24}

TABLE 202.—Vapor Pressure of Ethyl Alcohol *

Temp. C	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
	Vapor pressure in millimeters of mercury at 0° C									
0°	12.24	13.18	14.15	15.16	16.21	17.31	18.46	19.68	20.98	22.34
10	23.78	25.31	27.94	28.67	30.50	32.44	34.49	36.67	38.97	41.40
20	44.00	46.66	49.47	52.44	55.56	58.86	62.33	65.97	69.80	73.83
30	78.06	82.50	87.17	92.07	97.21	102.60	108.24	114.15	120.35	126.86
40	133.70	140.75	148.10	155.80	163.80	172.20	181.00	190.10	199.65	209.60
50	220.00	230.80	242.50	253.80	265.90	278.60	291.85	305.65	319.95	334.85
60	350.30	366.40	383.10	400.40	418.35	437.00	456.35	476.45	497.25	518.85
70	541.20	564.35	588.35	613.20	638.95	665.55	693.10	721.55	751.00	781.45

From the formula $\log p = a + b\alpha^t + c\beta^t$ Ramsay and Young obtain the following numbers.†

Temp. C	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
	Vapor pressure in millimeters of mercury at 0° C									
0°	12.24	23.73	43.97	78.11	133.42	219.82	350.21	540.91	811.81	1186.5
100	1692.3	2359.8	3223.0	4318.7	5686.6	7368.7	9409.9	11858.	14764.	18185.
200	22182.	26825.	32196.	38389.	45519.					

TABLE 203.—Vapor Pressure of Methyl Alcohol ‡

Temp. C	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
	Vapor pressure in millimeters of mercury at 0° C									
0°	29.97	31.6	33.6	35.6	37.8	40.2	42.6	45.2	47.9	50.8
10	53.8	57.0	60.3	63.8	67.5	71.4	75.5	79.8	84.3	89.0
20	94.0	99.2	104.7	110.4	116.5	122.7	129.3	136.2	143.4	151.0
30	158.9	167.1	175.7	184.7	194.1	203.9	214.1	224.7	235.8	247.4
40	259.4	271.9	285.0	298.5	312.6	327.3	342.5	358.3	374.7	391.7
50	409.4	427.7	446.6	466.3	486.6	507.7	529.5	552.0	575.3	599.4
60	624.3	650.0	676.5	703.8	732.0	761.1	791.1	822.0	–	–

* This table has been compiled from results published by Ramsay and Young (Jour. Chem. Soc. vol. 47, and Phil. Trans. Roy. Soc., 1886).

† In this formula $a = 5.0720301$; $\log b = \bar{2}.6406131$; $\log c = 0.6050854$; $\log \alpha = 0.003377538$; $\log \beta = \bar{1}.99682424$ (c is negative).

‡ Taken from a paper by Dittmar and Fawsitt (Trans. Roy. Soc. Edin. vol. 33).

Table 204

VAPOR PRESSURE *

Carbon Disulphide, Chlorobenzene, Bromobenzene, and Aniline

Temp. C	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
					(a) Carbon Disulphide.					
0°	127.90	133.85	140.05	146.45	153.10	160.00	167.15	174.60	182.25	190.20
10	198.45	207.00	215.80	224.95	234.40	244.15	254.25	264.65	275.40	286.55
20	298.05	309.90	322.10	334.70	347.70	361.10	374.95	389.20	403.90	419.00
30	434.60	450.65	467.15	484.15	501.65	519.65	538.15	557.15	576.75	596.85
40	617.50	638.70	660.50	682.90	705.90	729.50	753.75	778.60	804.10	830.25
					(b) Chlorobenzene.					
20°	8.65	9.14	9.66	10.21	10.79	11.40	12.04	12.71	13.42	14.17
30	14.95	15.77	16.63	17.53	18.47	19.45	20.48	21.56	22.69	23.87
40	25.10	26.38	27.72	29.12	30.58	32.10	33.69	35.35	37.08	38.88
50	40.75	42.69	44.72	46.84	49.05	51.35	53.74	56.22	58.79	61.45
60	64.20	67.06	70.03	73.11	76.30	79.60	83.02	86.56	90.22	94.00
70	97.90	101.95	106.10	110.41	114.85	119.45	124.20	129.10	134.15	139.40
80	144.80	150.30	156.05	161.95	168.00	174.25	181.70	187.30	194.10	201.15
90	208.35	215.80	223.45	231.30	239.35	247.70	256.20	265.00	274.00	283.25
100	292.75	302.50	312.50	322.80	333.35	344.15	355.25	366.65	378.30	390.25
110	402.55	415.10	427.95	441.15	454.65	468.50	482.65	497.20	512.05	527.25
120	542.80	558.70	575.05	591.70	608.75	626.15	643.95	662.15	680.75	699.65
130	718.95	738.65	758.80	–	–	–	–	–	–	–
					(c) Bromobenzene.					
40°	–	–	–	–	–	12.40	13.06	13.75	14.47	15.22
50	16.00	16.82	17.68	18.58	19.52	20.50	21.52	22.59	23.71	24.88
60	26.10	27.36	28.68	30.06	31.50	33.00	34.56	36.18	37.86	39.60
70	41.40	43.28	45.24	47.28	49.40	51.60	53.88	56.25	58.71	61.26
80	63.90	66.64	69.48	72.42	75.46	78.60	81.84	85.20	88.68	92.28
90	96.00	99.84	103.80	107.88	112.08	116.40	120.86	125.46	130.20	135.08
100	140.10	145.26	150.57	156.03	161.64	167.40	173.32	179.41	185.67	192.10
110	198.70	205.48	212.44	219.58	226.90	234.40	242.10	250.00	258.10	266.40
120	274.90	283.65	292.60	301.75	311.15	320.80	330.70	340.80	351.15	361.80
130	372.65	383.75	395.10	406.70	418.60	430.75	443.20	455.90	468.90	482.20
140	495.80	509.70	523.90	538.40	553.20	568.35	583.85	599.65	615.75	632.25
150	649.05	666.25	683.80	701.65	719.95	738.55	757.55	776.95	796.70	816.90
					(d) Aniline.					
80°	18.80	19.78	20.79	21.83	22.90	24.00	25.14	26.32	27.54	28.80
90	30.10	31.44	32.83	34.27	35.76	37.30	38.90	40.56	42.28	44.06
100	45.90	47.80	49.78	51.84	53.98	56.20	58.50	60.88	63.34	65.88
110	68.50	71.22	74.04	76.96	79.98	83.10	86.32	89.66	93.12	96.70
120	100.40	104.22	108.17	112.25	116.46	120.80	125.28	129.91	134.69	139.62
130	144.70	149.94	155.34	160.90	166.62	172.50	178.56	184.80	191.22	197.82
140	204.60	211.58	218.76	226.14	233.72	241.50	249.50	257.72	266.16	274.82
150	283.70	292.80	302.15	311.75	321.60	331.70	342.05	352.65	363.50	374.60
160	386.00	397.65	409.60	421.80	434.30	447.10	460.20	473.60	487.25	501.25
170	515.60	530.20	545.20	560.45	576.10	592.05	608.35	625.05	642.05	659.45
180	677.15	695.30	713.75	732.65	751.90	771.50	–	–	–	–

* These tables of vapor pressures are quoted from results published by Ramsay and Young (Jour. Chem. Soc. vol. 47). The tables are intended to give a series suitable for hot-jacket purposes.

VAPOR PRESSURE

Methyl Salicylate, Bromonaphthalene, and Mercury

Temp. C	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
					(e) METHYL SALICYLATE.					
70°	2.40	2.58	2.77	2.97	3.18	3.40	3.62	3.85	4.09	4.34
80	4.60	4.87	5.15	5.44	5.74	6.05	6.37	6.70	7.05	7.42
90	7.80	8.20	8.62	9.06	9.52	9.95	10.44	10.95	11.48	12.03
100	12.60	13.20	13.82	14.47	15.15	15.85	16.58	17.34	18.13	18.95
110	19.80	20.68	21.60	22.55	23.53	24.55	25.61	26.71	27.85	29.03
120	30.25	31.52	32.84	34.21	35.63	37.10	38.67	40.24	41.84	43.54
130	45.30	47.12	49.01	50.96	52.97	55.05	57.20	59.43	61.73	64.10
140	66.55	69.08	71.69	74.38	77.15	80.00	82.94	85.97	89.09	92.30
150	95.60	99.00	102.50	106.10	109.80	113.60	117.51	121.53	125.66	129.90
160	134.25	138.72	143.31	148.03	152.88	157.85	162.95	168.19	173.56	179.06
170	184.70	190.48	196.41	202.49	208.72	215.10	221.65	228.30	235.15	242.15
180	249.35	256.70	264.20	271.90	279.75	287.80	296.00	304.48	313.05	321.85
190	330.85	340.05	349.45	359.05	368.85	378.90	389.15	399.60	410.30	421.20
200	432.35	443.75	455.35	467.25	479.35	491.70	504.35	517.25	530.40	543.80
210	557.50	571.45	585.70	600.25	615.05	630.15	645.55	661.25	677.25	693.60
220	710.10	727.05	744.35	761.90	779.85	798.10				
					(f) BROMONAPHTHALENE.					
110	3.60	3.74	3.89	4.05	4.22	4.40	4.59	4.79	5.00	5.22
120	5.45	5.70	5.96	6.23	6.51	6.80	7.10	7.42	7.76	8.12
130	8.50	8.89	9.29	9.71	10.15	10.60	11.07	11.56	12.07	12.60
140	13.15	13.72	14.31	14.92	15.55	16.20	16.87	17.56	18.28	19.03
150	19.80	20.59	21.41	22.25	23.11	24.00	24.92	25.86	26.83	27.83
160	28.85	29.90	30.98	32.09	33.23	34.40	35.60	36.83	38.10	39.41
170	40.75	42.12	43.53	44.99	46.50	48.05	49.64	51.28	52.96	54.68
180	56.45	58.27	60.14	62.04	64.06	66.10	68.19	70.34	72.55	74.82
190	77.15	79.54	81.99	84.51	87.10	89.75	92.47	95.26	98.12	101.05
200	104.05	107.12	110.27	113.50	116.81	120.20	123.67	127.22	130.86	134.59
210	138.40	142.30	146.29	150.38	154.57	158.85	163.25	167.70	172.30	176.95
220	181.75	186.65	191.65	196.75	202.00	207.35	212.80	218.40	224.15	230.00
230	235.95	242.05	248.30	254.65	261.20	267.85	274.65	281.60	288.70	295.95
240	303.35	310.90	318.65	326.50	334.55	342.75	351.10	359.65	368.40	377.30
250	386.35	395.60	405.05	414.65	424.45	434.45	444.65	455.00	465.60	476.35
260	487.35	498.55	509.90	521.50	533.35	545.35	557.60	570.05	582.70	595.60
270	608.75	622.10	635.70	649.50	663.55	677.85	692.40	707.15	722.15	737.45
					(g) MERCURY.					
270°	123.92	126.97	130.08	133.26	136.50	139.81	143.18	146.61	150.12	153.70
280	157.35	161.07	164.86	168.73	172.67	176.79	180.88	185.05	189.30	193.63
290	198.04	202.53	207.10	211.76	216.50	221.33	226.25	231.25	236.34	241.53
300	246.81	252.18	257.65	263.21	268.87	274.63	280.48	286.43	292.49	298.66
310	304.93	311.30	317.78	324.37	331.08	337.89	344.81	351.85	359.00	366.28
320	373.67	381.18	388.81	396.56	404.43	412.44	420.58	428.83	437.22	445.75
330	454.41	463.20	472.12	481.19	490.40	499.74	509.22	518.85	528.63	538.56
340	548.64	558.87	569.25	579.78	590.48	601.33	612.34	623.51	634.85	646.36
350	658.03	669.86	681.86	694.04	706.40	718.94	731.65	744.54	757.61	770.87
360	784.31									

Table 205

VAPOR PRESSURE OF SOLUTIONS OF SALTS IN WATER *

The first column gives the chemical formula of the salt. The headings of the other columns give the number of gram-molecules of the salt in a liter of water. The numbers in these columns give the lowering of the vapor pressure produced by the salt at the temperature of boiling water under 76 centimeters barometric pressure.

Substance.	0.5	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0
$Al_2(SO_4)_3$	12.8	36.5							
$AlCl_3$	22.5	61.0	179.0	318.0					
BaS_2O_6	6.6	15.4	34.4						
$Ba(OH)_2$	12.3	22.5	39.0						
$Ba(NO_3)_2$	13.5	27.0							
$Ba(ClO_3)_2$	15.8	33.3	70.5	108.2					
$BaCl_2$	16.4	36.7	77.6						
$BaBr_2$	16.8	38.8	91.4	150.0	204.7				
CaS_2O_3	9.9	23.0	56.0	106.0					
$Ca(NO_3)_2$	16.4	34.8	74.6	139.3	161.7	205.4			
$CaCl_2$	17.0	39.8	95.3	166.6	241.5	319.5			
$CaBr_2$	17.7	44.2	105.8	191.0	283.3	368.5			
$CdSO_4$	4.1	8.9	18.1						
CdI_2	7.6	14.8	33.5	52.7					
$CdBr_2$	8.6	17.8	36.7	55.7	80.0				
$CdCl_2$	9.6	18.8	36.7	57.0	77.3	99.0			
$Cd(NO_3)_2$	15.9	36.1	78.0	122.2					
$Cd(ClO_3)_2$	17.5								
$CoSO_4$	5.5	10.7	22.9	45.5					
$CoCl_2$	15.0	34.8	83.0	136.0	186.4				
$Co(NO_3)_2$	17.3	39.2	89.0	152.0	218.7	282.0	332.0		
$FeSO_4$	5.8	10.7	24.0	42.4					
H_3BO_3	6.0	12.3	25.1	38.0	51.0				
H_3PO_4	6.6	14.0	28.6	45.2	62.0	81.5	103.0	146.9	189.5
H_3AsO_4	7.3	15.0	30.2	46.4	64.9				
H_2SO_4	12.9	26.5	62.8	104.0	148.0	198.4	247.0	343.2	
KH_2PO_4	10.2	19.5	33.3	47.8	60.5	73.1	85.2		
KNO_3	10.3	21.1	40.1	57.6	74.5	88.2	102.1	126.3	148.0
$KClO_3$	10.6	21.6	42.8	62.1	80.0				
$KBrO_3$	10.9	22.4	45.0						
$KHSO_4$	10.9	21.9	43.3	65.3	85.5	107.8	129.2	170.0	
KNO_2	11.1	22.8	44.8	67.0	90.0	110.5	130.7	167.0	198.8
$KClO_4$	11.5	22.3							
KCl	12.2	24.4	48.8	74.1	100.9	128.5	152.2		
$KHCO_3$	11.6	23.6	59.0	77.6	104.2	132.0	160.0	210.0	255.0
KI	12.5	25.3	52.2	82.6	112.2	141.5	171.8	225.5	278.5
$K_2C_2O_4$	13.9	28.3	59.8	94.2	131.0				
K_2WO_4	13.9	33.0	75.0	123.8	175.4	226.4			
K_2CO_3	14.4	31.0	68.3	105.5	152.0	209.0	258.5	350.0	
KOH	15.0	29.5	64.0	99.2	140.0	181.8	223.0	309.5	387.8
K_2CrO_4	16.2	29.5	60.0						
$LiNO_3$	12.2	25.9	55.7	88.9	122.2	155.1	188.0	253.4	309.2
$LiCl$	12.1	25.5	57.1	95.0	132.5	175.5	219.5	311.5	393.5
$LiBr$	12.2	26.2	60.0	97.0	140.0	186.3	241.5	341.5	438.0
Li_2SO_4	13.3	28.1	56.8	89.0					
$LiHSO_4$	12.8	27.0	57.0	93.0	130.0	168.0			
LiI	13.6	28.6	64.7	105.2	154.5	206.0	264.0	357.0	445.0
Li_2SiFl_6	15.4	34.0	70.0	106.0					
$LiOH$	15.9	37.4	78.1						
Li_2CrO_4	16.4	32.6	74.0	120.0	171.0				

* Compiled from a table by Tammann, "Mém. Ac. St. Petersb." 35, No. 9, 1887. See also Referate, "Zeit. f Phys." ch. 2, 42, 1886.

VAPOR PRESSURE OF SOLUTIONS OF SALTS IN WATER

Substance.	0.5	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0
$MgSO_4$	6.5	12.0	24.5	47.5					
$MgCl_2$	16.8	39.0	100.5	183.3	277.0	377.0			
$Mg(NO_3)_2$	17.6	42.0	101.0	174.8					
$MgBr_2$	17.9	44.0	115.8	205.3	298.5				
$MgH_2(SO_4)_2$	18.3	46.0	116.0						
$MnSO_4$	6.0	10.5	21.0						
$MnCl_2$	15.0	34.0	76.0	122.3	167.0	209.0			
NaH_2PO_4	10.5	20.0	36.5	51.7	66.8	82.0	96.5	126.7	157.1
$NaHSO_4$	10.9	22.1	47.3	75.0	100.2	126.1	148.5	189.7	231.4
$NaNO_3$	10.6	22.5	46.2	68.1	90.3	111.5	131.7	167.8	198.8
$NaClO_3$	10.5	23.0	48.4	73.5	98.5	123.3	147.5	196.5	223.5
$(NaPO_3)_6$	11.6								
$NaOH$	11.8	22.8	48.2	77.3	107.5	139.1	172.5	243.3	314.0
$NaNO_2$	11.6	24.4	50.0	75.0	98.2	122.5	146.5	189.0	226.2
Na_2HPO_4	12.1	23.5	43.0	60.0	78.7	99.8	122.1		
$NaHCO_3$	12.9	24.1	48.2	77.6	102.2	127.8	152.0	198.0	239.4
Na_2SO_4	12.6	25.0	48.9	74.2					
$NaCl$	12.3	25.2	52.1	80.0	111.0	143.0	176.5		
$NaBrO_3$	12.1	25.0	54.1	81.3	108.8	136.0			
$NaBr$	12.6	25.9	57.0	89.2	124.2	159.5	197.5	268.0	
NaI	12.1	25.6	60.2	99.5	136.7	177.5	221.0	301.5	370.0
$Na_4P_2O_7$	13.2	22.0							
Na_2CO_3	14.3	27.3	53.5	80.2	111.0				
$Na_2C_2O_4$	14.5	30.0	65.8	105.8	146.0				
Na_2WO_4	14.8	33.6	71.6	115.7	162.6				
Na_3PO_4	16.5	30.0	52.5						
$(NaPO_3)_3$	17.1	36.5							
NH_4NO_3	12.8	22.0	42.1	62.7	82.9	103.8	121.0	152.2	180.0
$(NH_4)_2SiFl_6$	11.5	25.0	44.5						
NH_4Cl	12.0	23.7	45.1	69.3	94.2	118.5	138.2	179.0	213.8
NH_4HSO_4	11.5	22.0	46.8	71.0	94.5	118.	139 0	181.2	218.0
$(NH_4)_2SO_4$	11.0	24.0	46.5	69.5	93.0	117.0	141.8		
NH_4Br	11.9	23.9	48.8	74.1	99.4	121.5	145.5	190.2	228.5
NH_4I	12.9	25.1	49.8	78.5	104.5	132.3	156.0	200.0	243.5
$NiSO_4$	5.0	10.2	21.5						
$NiCl_2$	16.1	37.0	86.7	147.0	212.8				
$Ni(NO_3)_2$	16.1	37.3	91.3	156.2	235.0				
$Pb(NO_3)_2$	12.3	23.5	45.0	63.0					
$Sr(SO_3)_2$	7.2	20.3	47.0						
$Sr(NO_3)_2$	15.8	31.0	64.0	97.4	131.4				
$SrCl_2$	16.8	38.8	91.4	156.8	223.3	281.5			
$SrBr_2$	17.8	42.0	101.1	179.0	267.0				
$ZnSO_4$	4.9	10.4	21.5	42.1	66.2				
$ZnCl_2$	9.2	18.7	46.2	75.0	107.0	153.0	195.0		
$Zn(NO_3)_2$	16.6	39.0	93.5	157.5	223.8				

PRESSURE OF SATURATED AQUEOUS VAPOR

The following tables for the pressure of saturated aqueous vapor are taken principally from the Fourth Revised Edition (1918) of the Smithsonian Meteorological Tables.

TABLE 206.—At Low Temperatures,—69° to 0° C over Ice

Temp.	0	1	2	3	4	5	6	7	8	9
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
−60	0.008	0.007	0.006	0.005	0.004	0.004	0.003	0.003	0.003	0.002
−50	0.029	0.026	0.023	0.020	0.017	0.015	0.013	0.012	0.010	0.009
−40	0.096	0.086	0.076	0.068	0.060	0.054	0.048	0.042	0.037	0.033
−30	0.288	0.259	0.233	0.209	0.188	0.169	0.151	0.135	0.121	0.108
−20	0.783	0.712	0.646	0.585	0.530	0.480	0.434	0.392	0.354	0.319
−10	1.964	1.798	1.644	1.503	1.373	1.252	1.142	1.041	0.947	0.861
− 0	4.580	4.220	3.887	3.578	3.291	3.025	2.778	2.550	2.340	2.144

TABLE 207.—At Low Temperatures, −16° to 0° C over Water

Temp.	0	1	2	3	4	5	6	7	8	9
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
−10°	2.144	1.979	1.826	1.684	1.551	1.429	1.315	—	—	—
− 0°	4.579	4.255	3.952	3.669	3.404	3.158	2.928	2.712	2.509	2.321

TABLE 208.—For Temperatures 0° to 374° C over Water

Temp.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
0°	4.580	4.614	4.647	4.681	4.715	4.750	4.784	4.819	4.854	4.889
1	4.924	4.960	4.996	5.032	5.068	5.105	5.142	5.179	5.216	5.254
2	5.291	5.329	5.368	5.406	5.445	5.484	5.523	5.562	5.602	5.642
3	5.682	5.723	5.763	5.804	5.846	5.887	5.929	5.971	6.013	6.056
4	6.098	6.141	6.185	6.228	6.272	6.316	6.361	6.406	6.450	6.496
5	6.541	6.587	6.633	6.680	6.726	6.773	6.820	6.868	6.916	6.964
6	7.012	7.061	7.110	7.159	7.209	7.259	7.309	7.360	7.410	7.462
7	7.513	7.565	7.617	7.669	7.722	7.775	7.828	7.882	7.936	7.991
8	8.045	8.100	8.156	8.211	8.267	8.324	8.380	8.437	8.494	8.552
9	8.610	8.669	8.727	8.786	8.846	8.906	8.966	9.026	9.087	9.148
10	9.21	9.27	9.33	9.40	9.46	9.52	9.59	9.65	9.72	9.78
11	9.85	9.91	9.98	10.04	10.11	10.18	10.25	10.31	10.38	10.45
12	10.52	10.59	10.66	10.73	10.80	10.87	10.94	11.02	11.09	11.16
13	11.24	11.31	11.38	11.46	11.53	11.61	11.68	11.76	11.84	11.92
14	11.99	12.07	12.15	12.23	12.31	12.39	12.47	12.55	12.63	12.71
15	12.79	12.88	12.96	13.04	13.13	13.21	13.30	13.38	13.47	13.56
16	13.64	13.73	13.82	13.91	14.00	14.08	14.17	14.26	14.36	14.45
17	14.54	14.63	14.73	14.82	14.91	15.01	15.10	15.20	15.29	15.39
18	15.49	15.58	15.68	15.78	15.88	15.98	16.08	16.18	16.28	16.39
19	16.49	16.59	16.70	16.80	16.91	17.01	17.12	17.22	17.33	17.44
20	17.55	17.66	17.77	17.88	17.99	18.10	18.21	18.32	18.44	18.55
21	18.66	18.78	18.90	19.01	19.13	19.25	19.36	19.48	19.60	19.72
22	19.84	19.96	20.09	20.21	20.33	20.46	20.58	20.71	20.83	20.96
23	21.09	21.22	21.34	21.47	21.60	21.73	21.87	22.00	22.13	22.26
24	22.40	22.53	22.67	22.80	22.94	23.08	23.22	23.36	23.50	23.64
25	23.78	23.92	24.06	24.21	24.35	24.50	24.64	24.79	24.94	25.09

TABLE 208 (*continued*)

PRESSURE OF SATURATED AQUEOUS VAPOR

For Temperatures 0° to 374° C over Water

Temp. C	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
25°	23.78	23.92	24.06	24.21	24.35	24.50	24.64	24.79	24.94	25.09
26	25.24	25.38	25.54	25.69	25.84	25.99	26.14	26.30	26.46	26.61
27	26.77	26.92	27.08	27.24	27.40	27.56	27.72	27.89	28.05	28.22
28	28.38	28.55	28.71	28.88	29.05	29.22	29.39	29.56	29.73	29.90
29	30.08	30.25	30.43	30.60	30.78	30.96	31.14	31.32	31.50	31.68
30	31.86	32.04	32.23	32.41	32.60	32.79	32.97	33.16	33.35	33.54
31	33.74	33.93	34.12	34.32	34.51	34.71	34.91	35.10	35.30	35.50
32	35.70	35.91	36.11	36.32	36.52	36.73	36.94	37.14	37.35	37.56
33	37.78	37.99	38.20	38.42	38.63	38.85	39.06	39.28	39.50	39.72
34	39.95	40.17	40.39	40.62	40.85	41.07	41.30	41.53	41.76	41.99
35	42.23	42.46	42.70	42.93	43.17	43.41	43.65	43.89	44.13	44.37
36	44.62	44.86	45.11	45.36	45.61	45.86	46.11	46.36	46.62	46.87
37	47.13	47.38	47.64	47.90	48.16	48.43	48.69	48.95	49.22	49.49
38	49.76	50.02	50.30	50.57	50.84	51.12	51.39	51.67	51.95	52.23
39	52.51	52.79	53.08	53.36	53.65	53.94	54.23	54.52	54.81	55.10
40	55.40	55.69	55.99	56.29	56.59	56.89	57.19	57.50	57.80	58.11
41	58.42	58.73	59.04	59.35	59.66	59.98	60.30	60.62	60.94	61.26
42	61.58	61.90	62.23	62.56	62.89	63.22	63.55	63.88	64.22	64.55
43	64.89	65.23	65.57	65.91	66.26	66.60	66.95	67.30	67.64	68.00
44	68.35	68.70	69.06	69.42	69.78	70.14	70.50	70.87	71.23	71.60
45	71.97	72.34	72.71	73.09	73.46	73.84	74.22	74.60	74.98	75.36
46	75.75	76.14	76.53	76.92	77.31	77.70	78.10	78.50	78.90	79.30
47	79.70	80.11	80.51	80.92	81.33	81.74	82.16	82.57	82.99	83.41
48	83.83	84.25	84.68	85.10	85.53	85.96	86.39	86.83	87.26	87.70
49	88.14	88.58	89.02	89.47	89.92	90.36	90.82	91.27	91.72	92.18
	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
50	92.6	97.3	102.2	107.3	112.7	118.2	124.0	130.0	136.3	142.8
60	149.6	156.6	164.0	171.6	179.5	187.8	196.3	205.2	214.4	224.0
70	233.9	244.2	254.9	266.0	277.4	289.3	301.6	314.4	327.6	341.2
80	355.4	370.0	385.2	400.8	417.0	433.7	451.0	468.8	487.3	506.3
90	526.0	546.3	567.2	588.8	611.1	634.1	657.8	682.2	707.4	733.3
100	760.0	787.5	815.9	845.0	875.1	906.0	937.8	970.5	1004.2	1038.8
110	1074	1111	1149	1187	1227	1268	1310	1353	1397	1442
120	1489	1536	1585	1636	1687	1740	1794	1850	1907	1965
130	2025	2086	2149	2214	2280	2347	2416	2487	2559	2633
140	2709	2786	2866	2947	3030	3115	3201	3290	3381	3473
150	3568	3665	3763	3864	3967	4072	4180	4290	4402	4516
160	4632	4751	4873	4997	5123	5252	5383	5518	5654	5794
170	5936	6080	6228	6378	6532	6688	6847	7009	7174	7342
180	7513	7688	7865	8046	8230	8417	8608	8802	8999	9200
190	9404	9612	9823	10040	10260	10480	10700	10940	11170	11410
200	11650	11890	12140	12400	12650	12920	13180	13450	13730	14010
210	14290	14580	14870	15160	15470	15770	16080	16400	16720	17040
220	17370	17710	18050	18390	18740	19100	19450	19820	20190	20560
230	20950	21330	21720	22120	22520	22930	23350	23770	24190	24620
240	25060	25500	25950	26410	26870	27340	27810	28290	28780	29270
250	29770	30280	30790	31310	31830	32360	32900	33450	34000	34560
260	35130	35700	36280	36870	37470	38070	38680	39300	39920	40560
270	41200	41840	42500	43160	43840	44520	45200	45900	46600	47320
280	48040	48760	49500	50250	51000	51770	52540	53320	54110	54910
290	55710	56530	57360	58190	59040	59890	60750	61620	62510	63400
300	64300	65210	66130	67060	68000	68960	69920	70890	71870	72860
310	73870	74880	75910	76940	77990	79050	80120	81200	82290	83390
320	84500	85630	86760	87910	89070	90250	91430	92630	93840	95060
330	96290	97530	98790	100060	101350	102640	103950	105280	106600	108000
340	109300	110700	112100	113500	114900	116300	117800	119200	120700	122200
350	123700	125200	126800	128300	129900	131400	133000	134600	136300	137900
360	139600	141200	142900	144600	146300	148100	149800	151600	153400	155200
370	157000	158800	160700	162600	164400	—	—	—	—	—

TABLE 209.—Weight in Grams of a Cubic Meter of Saturated Aqueous Vapor

Temp. °C	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
−20°	0.894	0.816	0.743	0.677	0.615	0.559	0.508	0.461	0.418	0.378
−10	2.158	1.983	1.820	1.671	1.531	1.403	1.284	1.174	1.073	0.980
− 0	4.847	4.482	4.144	3.828	3.534	3.261	3.006	2.770	2.551	2.347
+ 0°	4.847	5.192	5.559	5.947	6.360	6.797	7.261	7.751	8.271	8.821
+10	9.401	10.015	10.664	11.348	12.070	12.832	13.635	14.482	15.373	16.311
+20	17.300	18.338	19.430	20.578	21.783	23.049	24.378	25.771	27.234	28.765
+30	30.371	32.052	33.812	35.656	37.583	39.599	41.706	43.908	46.208	48.609

For higher temperatures, see Table 290.

TABLE 210.—Weight in Grains of a Cubic Foot of Saturated Aqueous Vapor

Temp. °F.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
−20°	0.167	0.158	0.150	0.141	0.134	0.126	0.119	0.112	0.106	0.100
−10	0.286	0.272	0.258	0.244	0.232	0.220	0.208	0.197	0.187	0.176
− 0	0.479	0.455	0.433	0.411	0.391	0.371	0.353	0.335	0.318	0.302
+ 0°	0.479	0.503	0.529	0.556	0.584	0.613	0.644	0.676	0.709	0.744
+10	0.780	0.818	0.858	0.900	0.943	0.988	1.035	1.084	1.135	1.189
+20	1.244	1.301	1.362	1.425	1.490	1.558	1.629	1.703	1.779	1.859
+30	1.942	2.028	2.118	2.200	2.286	2.375	2.466	2.560	2.658	2.759
+40	2.863	2.970	3.082	3.196	3.315	3.436	3.563	3.693	3.828	3.965
+50	4.108	4.255	4.407	4.564	4.725	4.891	5.062	5.238	5.420	5.607
+60	5.800	5.999	6.203	6.413	6.630	6.852	7.082	7.317	7.560	7.809
+70	8.066	8.329	8.600	8.879	9.165	9.460	9.761	10.072	10.392	10.720
+80	11.056	11.401	11.756	12.121	12.494	12.878	13.272	13.676	14.090	14.515
+90	14.951	15.400	15.858	16.328	16.810	17.305	17.812	18.330	18.863	19.407
100°	19.966	20.538	21.123	21.723	22.337	22.966	23.611	24.271	24.946	25.636
110	26.343	27.066	27.807	28.563	29.338	30.130	30.940	31.768	32.616	33.482

Tables are abridged from Smithsonian Meteorological Tables, fourth revised edition.

TABLE 211.—Pressure of Aqueous Vapor in the Atmosphere

For various altitudes (barometric readings).

The first column gives the depression of the wet-bulb temperature t_1 below the air temperature t. The value corresponding to the barometric height at the altitude of observation is to be subtracted from the vapor pressure corresponding to the wet-bulb temperature taken from Table 208. The temperature corresponding to this vapor pressure taken from Table 208 is the dew point. The wet bulb should be ventilated about 3 meters per second. For sea-level use Table 212. Example: $t = 35°$, $t_1 = 30°$, barometer 74 cm. Then $31.83 - 2.46 = 29.37$ mm = aqueous vapor pressure; the dew point is 28.6° C.

Abridged from Smithsonian Meteorological Tables, 1907.

$t - t_1$ °C	Barometric pressure in centimeters.													
	74	**72**	**70**	**68**	**66**	**64**	**62**	**60**	**58**	**56**	**54**	**52**	**50**	**48**
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
1°	0.50	0.48	0.47	0.46	0.44	0.43	0.42	0.40	0.39	0.38	0.36	0.35	0.34	0.32
2	0.98	0.96	0.93	0.90	0.88	0.85	0.82	0.80	0.77	0.75	0.72	0.69	0.67	0.64
3	1.47	1.43	1.39	1.35	1.32	1.28	1.24	1.20	1.15	1.12	1.08	1.04	1.00	0.96
4	1.97	1.91	1.86	1.81	1.75	1.70	1.65	1.60	1.54	1.49	1.44	1.38	1.33	1.28
5	2.46	2.39	2.32	2.26	2.19	2.13	2.06	1.99	1.93	1.86	1.80	1.73	1.66	1.60
6	2.95	2.87	2.79	2.71	2.63	2.55	2.47	2.39	2.32	2.24	2.16	2.08	2.00	1.92
7	3.45	3.36	3.26	3.17	3.08	2.99	2.89	2.80	2.71	2.61	2.52	2.43	2.33	2.24
8	3.95	3.84	3.73	3.63	3.53	3.42	3.31	3.20	3.10	2.99	2.88	2.78	2.67	2.56
9	4.44	4.32	4.21	4.09	3.97	3.85	3.73	3.61	3.49	3.37	3.25	3.13	3.00	2.88
10	4.94	4.81	4.68	4.54	4.41	4.28	4.14	4.01	3.88	3.74	3.61	3.48	3.34	3.21
11	5.44	5.30	5.15	5.00	4.86	4.71	4.56	4.42	4.27	4.12	3.97	3.83	3.68	3.53
12	5.94	5.78	5.62	5.46	5.30	5.14	4.98	4.82	4.66	4.50	4.34	4.18	4.02	3.85
13	6.45	6.27	6.10	5.92	5.75	5.57	5.40	5.23	5.05	4.88	4.70	4.53	4.36	4.18
14	6.95	6.76	6.58	6.39	6.20	6.01	5.83	5.64	5.45	5.26	5.07	4.88	4.70	4.51
15	7.46	7.26	7.06	6.85	6.65	6.45	6.25	6.05	5.85	5.64	5.44	5.24	5.04	4.84
16	7.96	7.75	7.54	7.32	7.11	6.89	6.68	6.46	6.24	6.03	5.81	5.60	5.38	5.17
17	8.47	8.24	8.02	7.79	7.56	7.33	7.10	6.87	6.64	6.41	6.18	5.95	5.72	5.50

TABLE 212

PRESSURE OF AQUEOUS VAPOR IN THE ATMOSPHERE: SEA-LEVEL

This table gives the vapor pressure corresponding to various values of the difference $t - t_1$ between the readings of dry and wet bulb thermometers and the temperature t_1 of the wet bulb thermometer. The difference $t - t_1$ is given by two-degree steps in the top line, and t_1 by degrees in the first column. Temperatures in Centigrade degrees, vapor pressures in millimeters of mercury are used throughout the table. The table was calculated for barometric pressure B equal to 76 centimeters. A correction is given for each centimeter at the top of the columns. Ventilating velocity of wet thermometer about 3 meters per second.

t_1	$t - t_1 = 0°$	2°	4°	6°	8°	10°	12°	14°	16°	18°	20°	Difference for 0.1° in $t - t_1$
Corrections for B per cm		.013	.026	.040	.053	.066	.079	.092	.106	.119	.132	
−10	1.96	0.97	—	—	—							0.050
− 9	2.14	1.15	0.16	—	—							0.050
− 8	2.34	1.35	0.35	—	—							0.050
− 7	2.55	1.56	0.66	—	—							0.050
− 6	2.78	1.78	0.79	—	—							0.050
− 5	3.02	2.03	1.03	0.03	—							0.050
− 4	3.29	2.29	1.29	0.29	—							0.050
− 3	3.58	2.58	1.58	0.58	—							0.050
− 2	3.89	2.89	1.89	0.88	—	—	—	—	—	—	—	0.050
− 1	4.22	3.22	2.22	1.21	0.21	—	—	—	—	—	—	0.050
0	4.58	3.58	2.57	1.57	0.57	—	—	—	—	—	—	0.050
1	4.92	3.92	2.92	1.91	0.91	—	—	—	—	—	—	0.050
2	5.29	4.29	3.28	2.27	1.27	0.26	—	—	—	—	—	0.050
3	5.68	4.68	3.67	2.66	1.66	0.65	—	—	—	—	—	0.050
4	6.10	5.09	4.08	3.07	2.07	1.06	0.05	—	—	—	—	0.050
5	6.54	5.53	4.52	3.51	2.51	1.50	0.49	—	—	—	—	0.050
6	7.01	6.00	4.99	3.98	2.97	1.96	0.95	—	—	—	—	0.050
7	7.51	6.50	5.49	4.48	3.47	2.46	1.45	0.43	—	—	—	0.050
8	8.04	7.03	6.02	5.01	4.00	2.98	1.97	0.96	—	—	—	0.050
9	8.61	7.60	6.58	5.57	4.56	3.54	2.53	1.52	0.50	—	—	0.050
10	9.21	8.20	7.18	6.17	5.15	4.14	3.12	2.11	1.09	0.03	—	0.050
11	9.85	8.83	7.81	6.80	5.78	4.77	3.75	2.73	1.72	0.70	—	0.051
12	10.52	9.50	8.49	7.47	6.45	5.44	4.42	3.40	2.38	1.37	0.35	0.051
13	11.24	10.22	9.20	8.18	7.16	6.14	5.13	4.11	3.09	2.07	1.05	0.051
14	11.99	10.97	9.95	8.93	7.91	6.90	5.88	4.86	3.84	2.82	1.80	0.051
15	12.79	11.77	10.75	9.73	8.71	7.69	6.67	5.65	4.63	3.61	2.59	0.051
16	13.64	12.62	11.60	10.58	9.96	8.53	7.51	6.49	5.47	4.45	3.43	0.051
17	14.54	13.52	12.49	11.47	10.45	9.42	8.40	7.38	6.36	5.33	4.31	0.051
18	15.49	14.46	13.44	12.42	11.39	10.37	9.34	8.32	7.30	6.27	5.25	0.051
19	16.49	15.46	14.44	13.41	12.39	11.36	10.34	9.31	8.29	7.26	6.24	0.051
20	17.55	16.52	15.50	14.47	13.44	12.42	11.39	10.36	9.34	8.31	7.29	0.051
21	18.66	17.64	16.61	15.58	14.56	13.53	12.50	11.47	10.45	9.42	8.39	0.051
22	19.84	18.82	17.79	16.76	15.73	14.70	13.67	12.64	11.62	10.59	10.57	0.051
23	21.09	20.06	19.03	18.00	16.97	15.94	14.91	13.88	12.85	11.82	10.79	0.051
24	22.40	21.37	20.34	19.31	18.27	17.24	16.21	15.18	14.15	13.12	12.09	0.051
25	23.78	22.75	21.71	20.68	19.65	18.62	17.59	16.56	15.52	14.49	13.46	0.052
26	25.24	24.20	23.17	22.14	21.10	20.07	19.04	18.00	16.97	15.94	14.90	0.052
27	26.77	25.73	24.70	23.66	22.63	21.60	20.56	19.53	18.49	17.46	16.42	0.052
28	28.38	27.34	26.31	25.27	24.24	23.20	22.17	21.13	20.10	19.06	13.02	0.052
29	30.08	29.04	28.00	26.97	25.93	24.89	23.86	22.82	21.78	20.75	19.71	0.052
30	31.86	30.82	29.78	28.75	27.71	26.67	25.63	24.60	23.56	22.52	21.48	0.052
31	33.74	32.70	31.66	30.62	29.58	28.54	27.50	26.46	25.42	24.38	23.34	0.052
32	35.70	34.66	33.62	32.58	31.54	30.50	29.46	28.42	27.38	26.34	25.30	0.052
33	37.78	36.73	35.69	34.65	33.61	32.57	31.53	30.49	29.44	28.40	27.36	0.052
34	39.95	38.90	37.86	36.82	35.78	34.73	33.69	32.65	31.61	30.57	29.52	0.052
35	42.23	41.18	40.14	39.10	38.05	37.01	35.97	34.92	33.88	32.83	31.79	0.052
36	44.62	43.57	42.53	41.48	40.44	39.40	38.35	37.31	36.26	35.22	34.17	0.052
37	47.13	46.08	45.04	43.99	42.94	41.90	40.85	39.81	38.76	37.71	36.67	0.052
38	49.76	48.71	47.66	46.61	45.57	44.52	43.47	42.43	41.38	40.33	39.29	0.052
39	52.51	51.46	50.41	49.37	48.32	47.27	46.22	45.17	44.12	43.08	42.03	0.052
40	55.40	54.35	53.30	52.25	51.20	50.15	49.10	48.05	47.00	45.95	44.00	0.052

Example.

$t = 17.2$; $t_1 = 10.0$; $B = 74.5$ cm
$t - t_1 = 7.2$
From table: $6.17 - 12 \times 0.050 = 5.57$
For B, $1.5 \times .048 \quad = \quad .07$
Hence $p \quad = 5.64$

Table 213

RELATIVE HUMIDITY, VAPOR PRESSURE AND DRY TEMPERATURE

Vertical argument is the observed vapor pressure which may be computed from the wet and dry-bulb readings through Table 211 or 212. The horizontal argument is the observed air temperature (dry-bulb reading). Based upon Table 43, p. 142, Smithsonian Meteorological Tables, 3d Revised Edition, 1907.

Vapor Pressure mm.	Air Temperatures, dry bulb, ° Centigrade.																
	0°	−1°	−2°	−3°	−4°	−5°	−6°	−7°	−8°	−9°	−10°	−11°	−12°	−13°	−14°	−15°	−20°
0.25	6	6	6	7	8	8	9	10	11	12	13	14	15	17	18	20	32
0.50	11	12	13	14	15	17	18	20	21	23	25	28	30	34	37	40	64
0.75	17	18	19	21	23	25	27	30	32	35	38	42	46	50	55	60	96
1.00	22	24	26	28	30	33	36	40	42	47	51	56	61	67	74	80	
1.25	27	30	32	35	38	42	45	49	54	58	64	70	76	84	92	100	
1.50	33	36	39	42	46	50	54	59	64	70	76	84	92	100			
1.75	38	42	45	49	53	58	63	69	75	82	89	98					
2.00	44	48	52	56	61	66	72	79	86	93							
2.25	49	53	58	63	69	75	81	89	96	–							
2.50	55	59	65	70	76	83	90	99	–	–							
2.75	60	65	71	77	84	91	100	–	–	–							
3.00	66	71	78	84	92	100	–	–	–	–							
3.25	71	77	84	91	99	–	–	–	–	–							
3.50	77	83	90	98	–	–	–	–	–	–							

mm.	0°	−1°	−2°	−3°
3.50	77	83	90	98
3.75	82	89	97	–
4.00	88	95	–	–
4.25	93	100	–	–
4.50	99	–	–	–

Vapor Pressure. mm.	Air Temperatures, dry bulb, ° Centigrade.																				
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	18°	19°	20°
0.5	11	10	9	9	8	8	7	7	6	6	5	5	5	4	4	4	4	3	3	3	3
1.0	22	20	19	18	16	15	14	13	13	12	11	10	10	9	8	8	7	7	7	6	6
1.5	33	31	28	27	25	23	22	20	19	18	16	15	14	13	13	12	11	10	10	9	9
2.0	44	41	38	35	33	31	29	27	25	23	22	20	19	18	17	16	15	14	13	12	12
2.5	55	51	47	44	41	38	36	33	31	29	27	26	24	22	21	20	18	17	16	15	14
3.0	66	61	57	53	49	46	43	40	38	35	33	31	29	27	25	24	22	21	20	18	17
3.5	77	71	66	62	58	54	50	47	44	41	38	36	34	31	29	28	26	24	23	21	20
4.0	88	81	76	71	66	61	57	54	50	47	44	41	38	36	34	32	30	28	26	25	23
4.5	99	92	85	80	74	69	65	60	56	53	49	46	43	40	38	36	33	31	29	28	26
5.0	–	–	95	88	83	77	72	67	63	58	55	51	48	45	42	39	37	35	33	31	29
5.5	–	–	–	97	91	85	79	74	69	64	60	56	53	49	46	43	41	38	36	34	32
6.0	–	–	–	–	99	92	86	80	75	70	66	61	58	54	51	47	44	42	39	37	34
6.5	–	–	–	–	–	100	93	87	81	76	71	67	62	58	55	51	48	45	42	40	37
7.0	–	–	–	–	–	–	100	94	85	82	77	72	67	63	59	55	52	49	46	43	40
7.5	–	–	–	–	–	–	–	100	94	88	82	77	72	67	63	59	55	52	49	46	43
8.0	–	–	–	–	–	–	–	–	100	94	88	82	77	72	67	63	59	56	52	49	46
8.5	–	–	–	–	–	–	–	–	–	99	93	87	82	76	72	67	63	59	55	52	49
9.0	–	–	–	–	–	–	–	–	–	–	98	92	86	81	76	71	67	62	59	55	52
9.5	–	–	–	–	–	–	–	–	–	–	–	97	91	85	80	75	70	66	62	58	55
10.0	–	–	–	–	–	–	–	–	–	–	–	–	96	90	84	79	74	69	65	61	57
11.0	–	–	–	–	–	–	–	–	–	–	–	–	–	94	93	87	81	76	72	67	63
12.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	94	89	83	78	74	69
13.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	96	90	85	80	75
14.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	97	91	86	80
15.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	97	92	86
16.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	98	92
17.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	98

RELATIVE HUMIDITY, VAPOR PRESSURE AND DRY TEMPERATURE

Vapor Pressure. mm.	Air Temperatures, dry bulb, ° Centigrade.																				
	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	30°	31°	32°	33°	34°	35°	36°	37°	38°	39°	40°
1	6	5	5	5	5	4	4	4	4	3	3	3	3	3	3	3	2	2	2	2	2
2	12	11	10	10	9	8	8	8	7	7	6	6	6	5	5	5	5	4	4	4	4
3	17	16	15	14	14	13	12	11	11	10	10	9	9	8	8	7	7	6	6	6	5
4	23	22	20	19	18	17	16	15	14	13	13	12	11	11	10	10	9	9	8	8	7
5	29	27	25	24	23	21	20	19	18	17	16	15	14	13	13	12	11	11	10	10	9
6	34	32	31	29	27	26	24	23	21	20	19	18	17	16	15	14	14	13	12	12	11
7	40	38	36	34	32	30	28	26	25	24	22	21	20	19	18	17	16	15	14	13	13
8	46	43	41	38	36	34	32	30	29	27	25	24	23	21	20	19	18	17	16	15	15
9	52	49	46	43	41	38	36	34	32	30	29	27	25	24	23	22	20	19	18	17	16
10	57	54	51	48	45	43	40	38	36	34	32	30	28	27	25	24	23	21	20	19	18
11	63	60	56	53	50	47	44	42	39	37	35	33	31	29	28	26	25	24	22	21	20
12	69	65	61	58	54	51	48	45	43	40	38	36	34	32	30	29	27	26	24	23	22
13	75	70	66	62	59	55	52	49	46	44	41	39	37	35	33	31	29	28	26	25	24
14	80	76	71	67	63	60	56	53	50	47	44	42	40	37	35	33	32	30	28	27	26
15	86	81	76	72	68	64	60	57	53	50	48	45	42	40	38	36	34	32	30	29	27
16	92	87	82	77	72	68	64	60	57	54	51	48	45	43	41	38	36	34	32	31	29
17	98	92	87	81	77	72	68	64	61	57	54	51	48	45	43	41	38	36	34	33	31
18	–	97	92	86	81	77	72	68	64	60	57	54	51	48	46	43	41	39	37	35	33
19	–	–	97	91	86	81	76	72	68	64	60	57	54	51	48	45	43	41	39	36	35
20	–	–	–	96	90	85	80	76	71	67	63	60	57	53	51	48	45	43	41	38	36
21	–	–	–	–	95	89	84	79	75	71	67	63	59	56	53	50	48	45	43	40	38
22	–	–	–	–	100	94	88	83	78	74	70	66	62	59	56	53	50	47	45	42	40
23	–	–	–	–	–	98	92	87	82	77	73	69	65	62	58	55	52	49	47	44	42
24	–	–	–	–	–	–	96	91	85	81	76	72	68	64	61	57	54	51	49	46	44
25	–	–	–	–	–	–	100	94	89	84	79	75	71	67	63	60	56	54	51	48	46
26	–	–	–	–	–	–	–	98	93	87	83	78	74	70	66	62	59	56	53	50	47
27	–	–	–	–	–	–	–	–	96	91	86	81	76	72	68	65	61	58	55	52	49
28	–	–	–	–	–	–	–	–	100	94	89	84	79	75	71	67	63	60	57	54	51
29	–	–	–	–	–	–	–	–	–	97	92	87	82	78	73	69	65	62	59	56	53
30	–	–	–	–	–	–	–	–	–	–	95	90	85	80	76	72	68	64	61	58	55
31	–	–	–	–	–	–	–	–	–	–	98	93	88	83	78	74	70	66	63	60	56
32	–	–	–	–	–	–	–	–	–	–	–	96	91	86	81	77	72	69	65	62	58
33	–	–	–	–	–	–	–	–	–	–	–	99	93	88	84	79	75	71	67	63	60
34	–	–	–	–	–	–	–	–	–	–	–	–	96	91	86	81	77	73	69	65	62
35	–	–	–	–	–	–	–	–	–	–	–	–	99	94	89	84	79	75	71	67	64
36	–	–	–	–	–	–	–	–	–	–	–	–	–	96	91	86	81	77	73	69	66
37	–	–	–	–	–	–	–	–	–	–	–	–	–	99	94	89	84	79	75	71	67
38	–	–	–	–	–	–	–	–	–	–	–	–	–	–	96	91	86	81	77	73	69
39	–	–	–	–	–	–	–	–	–	–	–	–	–	–	99	93	88	83	79	75	71
40	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	96	90	86	81	77	73
41	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	98	93	88	83	79	75
42	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	95	90	85	81	77
43	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	97	92	87	83	78
44	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	99	94	89	84	80
45	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	96	91	86	82
46	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	99	93	88	84
47	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	95	90	86
48	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	97	92	87
49	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	99	94	89
50	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	96	91
51	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	98	93
52	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	95
53	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	97
54	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	98
55	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100

TABLE 213 (*concluded*)—Relative Humidity, Vapor Pressure and Dry Temperature

(Data from 20° to 60° C based upon Table 208.)

Vapor Pressure. mm.	Air Temperatures, dry bulb, ° Centigrade.																				
	40°	41°	42°	43°	44°	45°	46°	47°	48°	49°	50	51°	52°	53°	54°	55°	56°	57°	58°	59°	60°
5	9	9	8	8	7	7	7	6	6	6	5	5	5	5	4	4	4	4	4	4	3
10	18	17	16	15	15	14	13	13	12	11	11	10	10	9	9	8	8	8	7	7	7
15	27	26	24	23	22	21	20	19	18	17	16	15	15	14	13	13	12	12	11	10	10
20	36	34	33	31	29	28	26	25	24	23	22	21	20	19	18	17	16	15	15	14	13
25	45	43	41	39	37	35	33	31	30	28	27	26	24	23	22	21	20	19	18	18	17
30	54	51	49	46	44	42	40	38	36	34	32	31	29	28	27	25	24	23	22	21	20
35	63	60	57	54	51	49	46	44	42	40	38	36	34	33	31	30	28	27	26	25	23
40	72	68	65	62	59	56	53	50	48	45	43	41	39	37	36	34	32	31	29	28	27
45	81	77	73	69	66	63	59	57	54	51	49	46	44	42	40	38	36	35	33	32	30
50	90	86	81	77	73	70	66	63	60	57	54	51	49	47	44	42	40	38	37	35	33
55	99	94	89	85	81	76	73	69	66	62	59	57	54	51	49	46	44	42	40	39	37
60	–	–	98	93	88	83	79	75	72	68	65	62	60	56	53	51	48	46	44	42	40
65	–	–	–	100	95	90	86	82	78	74	70	67	64	61	58	55	52	50	48	46	43
70	–	–	–	–	–	97	92	88	84	80	76	72	68	65	62	59	56	54	51	49	47
75	–	–	–	–	–	–	99	94	90	85	81	77	74	70	67	64	60	58	55	53	50
80	–	–	–	–	–	–	–	100	96	91	86	82	78	75	71	68	64	62	59	56	54
85	–	–	–	–	–	–	–	–	–	97	92	87	84	79	75	72	69	65	62	60	57
90	–	–	–	–	–	–	–	–	–	–	97	93	88	84	80	76	73	69	66	63	60
95	–							–	–	–	–	98	94	89	84	80	77	73	70	67	64
100	–							–	–	–	–	–	98	93	89	85	81	77	73	70	67
105	–							–	–	–	–	–	–	98	93	89	85	81	77	74	70
110	–							–	–	–	–	–	–	–	98	93	89	85	81	77	74
115	–							–	–	–	–	–	–	–	–	97	93	88	84	81	77
120	–							–	–	–	–	–	–	–	–	–	97	92	88	84	80
125	–							–	–	–	–	–	–	–	–	–	–	96	92	88	84

mm.	57°	58°	59°	60°
125	96	92	88	84
130	100	95	91	87
135	–	99	95	90
140	–	–	98	94
145	–	–	–	97
150	–	–	–	100

TABLE 214.—Relative Humidity, Wet and Dry Thermometers

This table gives the relative humidity direct from the difference between the reading of the dry (t ° C) and the wet (t_1 ° C) thermometer. It is computed for a barometer reading of 76 cm. The wet thermometer should be ventilated about 3 meters per second. From manuscript tables computed at the U.S. Weather Bureau.

t°	Depression of wet-bulb thermometer, $t°-t_1°$.																
	0.2°	0.4°	0.6°	0.8°	1.0°	1.2°	1.4°	1.6°	1.8°	2.0°	2.5°	3.0°	3.5°	4.0°	4.5°	5.0°	5.5°
−15	90	91	72	62	53	44	35	25	16	7	–	–	–	–	–	–	–
−12	92	85	77	69	62	54	47	39	32	25	7	–	–	–	–	–	–
−9	94	88	81	75	70	62	56	50	44	39	23	9	–	–	–	–	–
−6	95	89	85	80	74	69	64	59	54	49	36	25	13	2	–	–	–
−3	96	91	87	82	78	74	69	66	61	57	46	36	26	17	7	–	–
0	96	92	89	85	81	78	74	71	67	64	55	46	38	29	21	13	6
+3	97	94	91	87	84	81	78	75	72	69	62	54	46	40	32	25	18
	0.5°	1.0°	1.5°	2.0°	2.5°	3.0°	3.5°	4.0°	4.5°	5.0°	6.0°	7.0°	8.0°	9.0°	10.°	11.°	12.°
+3	92	84	76	69	62	54	46	40	32	25	12	–	–	–	–	–	–
+6	94	87	80	73	66	60	54	47	41	35	23	11	–	–	–	–	–
+9	94	88	82	76	70	65	59	53	48	42	32	22	12	3	–	–	–
+12	94	89	84	78	73	68	63	58	53	48	38	30	21	12	4	–	–
+15	95	90	85	80	76	71	66	62	58	53	44	36	28	20	13	4	–
+18	95	90	86	82	78	73	69	65	61	57	49	42	35	27	20	13	6
+21	96	91	87	83	79	75	71	67	64	60	53	46	39	32	26	19	13
+24	96	92	88	85	81	77	74	70	66	63	56	49	43	37	31	26	21
+27	96	93	90	86	82	79	76	72	68	65	59	53	47	41	36	31	26
+30	96	93	90	86	82	79	76	73	70	67	61	55	50	44	39	35	30
+33	96	93	90	86	83	80	77	74	71	68	63	57	52	47	42	37	33
+36	97	93	90	87	84	81	78	75	72	70	64	57	54	50	45	41	36
+39	97	94	91	88	85	82	79	76	74	71	66	61	56	52	47	43	39

THE INTERNATIONAL TEMPERATURE SCALE

(Adapted from G. K. Burgess, Bur. Standards Journ. Res., 1, 635, 1928.)

The Thermodynamic Centigrade Scale, on which the temperature of melting ice, and the temperature of condensing water vapor, both under the pressure of one standard atmosphere, are numbered 0° and 100°, respectively, is recognized as the fundamental scale to which all temperature measurements should ultimately be referable.

The experimental difficulties incident to the practical realization of the thermodynamic scale have made it expedient to adopt for international use a practical scale designated as the International Temperature Scale. This scale conforms with the thermodynamic scale as closely as is possible with present knowledge, and is designed to be definite, conveniently and accurately reproducible, and to provide means for uniquely determining any temperature within the range of the scale, thus promoting uniformity in numerical statements of temperature.

Temperatures on the international scale will ordinarily be designated as "°C," but may be designated as "°C (Int.)" if it is desired to emphasize the fact that this scale is being used.

The International Temperature Scale is based upon a number of fixed and reproducible equilibrium temperatures to which numerical values are assigned, and upon the indications of interpolation instruments calibrated according to a specified procedure at the fixed temperatures.

The basic fixed points and the numerical values assigned to them for the pressure of one standard atmosphere are given in the following table, together with formulas which represent the temperature (t_p) as a function of vapor pressure (p) over the range 680 to 780 mm of mercury.

Basic Fixed Points of the International Temperature Scale

	°C
(*a*) Temperature of equilibrium between liquid and gaseous oxygen at the pressure of one standard atmosphere (oxygen point).	−182.97
$t_p = t_{760} + 0.0126(p-760) - 0.0000065(p-760)^2$	
(*b*) Temperature of equilibrium between ice and air-saturated water at normal atmospheric pressure (ice point)	0.000
(*c*) Temperature of equilibrium between liquid water and its vapor at the pressure of one standard atmosphere (steam point) . .	100.000
$t_p = t_{760} + +0.0367(p-760) - 0.000023(p-760)^2$	
(*d*) Temperature of equilibrium between liquid sulphur and its vapor at the pressure of one standard atmosphere (sulphur point)	444.60
$t_p = t_{760} + 0.0909(p-760) - 0.000048(p-760)^2$	
(*e*) Temperature of equilibrium between solid silver and liquid silver at normal atmospheric pressure (silver point)	960.5
(*f*) Temperature of equilibrium between solid gold and liquid gold at normal atmospheric pressure (gold point)	1,063

THE INTERNATIONAL TEMPERATURE SCALE

Standard atmospheric pressure is defined as the pressure due to a column of mercury 760 mm high, having a mass of 13.5951 g/cm³, subject to a gravitational acceleration of 980.665 cm/sec.² and is equal to 1,013,250 dynes/cm².

It is an essential feature of a practical scale of temperature that definite numerical values shall be assigned to such fixed points as are chosen. It should be noted, however, that the last decimal place given for each of the values in the table is significant only as regards the degree of reproducibility of that fixed point on the International Temperature Scale. It is not to be understood that the values are necessarily known on the Thermodynamic Centigrade Scale to the corresponding degree of accuracy.

The means available for interpolation lead to a division of the scale into four parts.

(*a*) From the ice point to 660° C the temperature t is deduced from the resistance R_t of a standard platinum resistance thermometer by means of the formula

$$R_t = R_0(1 + A_t + Bt^2)$$

The constants R_0, A, and B of this formula are to be determined by calibration at the ice, steam, and sulphur points, respectively.

The purity and physical condition of the platinum of which the thermometer is made should be such that the ratio R_t/R_0 shall not be less than 1.390 for $t = 100°$ and 2.645 for $t = 444.6°$.

(*b*) From −190° to the ice point, the temperature t is deduced from the resistance R_t of a standard platinum resistance thermometer by means of the formula

$$R_t = R_0[1 + At + Bt^2 + C(t - 100)t^3]$$

The constants R_0, A, and B are to be determined as specified above, and the additional constant C is determined by calibration at the oxygen point.

The standard thermometer for use below 0° C must, in addition, have a ratio R_t/R_0 less than 0.250 for $t = -183°$.

(*c*) From 660° C to the gold point, the temperature t is deduced from the electromotive force e of a standard platinum *v.* platinum-rhodium thermocouple, one junction of which is kept at a constant temperature of 0° C while the other is at the temperature t defined by the formula

$$e = a + bt + ct^2$$

The constants a, b, and c are to be determined by calibration at the freezing point of antimony, and at the silver and gold points.

(*d*) Above the gold point the temperature t is determined by means of the ratio of the intensity J_2 of monochromatic visible radiation of wave length λ cm, emitted by a black body at the temperature t_2, to the intensity J_1 of radiation of the same wave length emitted by a black body at the gold point, by means of the formula

$$\log_e \frac{J_2}{J_1} = \frac{c_2}{\lambda}\left[\frac{1}{1{,}336} - \frac{1}{(t+273)}\right]$$

The constant c_2 is taken as 1.432 cm degrees. The equation is valid if $\lambda(t+273)$ is less than 0.3 cm degrees.

THE INTERNATIONAL TEMPERATURE SCALE

Recommended Procedure for Calibration

1. OXYGEN

The temperature of equilibrium of liquid and gaseous oxygen has been best realized experimentally by the static method, the oxygen vapor-pressure thermometer being compared with the thermometer to be standardized in a suitable low temperature bath.

2. ICE

The temperature of melting ice is realized experimentally as the temperature at which pure, finely divided ice is in equilibrium with pure, air-saturated water under standard atmospheric pressure. The effect of increased pressure is to lower the freezing point to the extent of 0.007° C per atmosphere.

3. STEAM

The temperature of condensing water vapor is realized experimentally by the use of a hypsometer so constructed as to avoid superheat of the vapor around the thermometer, or contamination with air or other impurities. If the desired conditions have been attained, the observed temperature should be independent of the rate of heat supply to the boiler, except as this may affect the pressure within the hypsometer, and of the length of time the hypsometer has been in operation.

4. SULPHUR

For the purpose of standardizing resistance thermometers, the temperature of condensing sulphur vapor is realized by adherence to the following specifications relating to boiling apparatus, purity of sulphur, radiation shield, and procedure.

The boiling-tube is of glass, fused silica, or similar material, and has an internal diameter of not less than 4 nor more than 6 cm. The vapor column must be sufficiently long that the bottom of the radiation shield is not less than 6 cm above the free liquid surface and its top is not less than 2 cm below the top of the heat insulating material surrounding the tube. Electric heating is preferable, although gas may be used, but the source of heat and all good conducting material in contact with it must terminate at least 4 cm below the free surface of the liquid sulphur. Above the source of heat the tube is surrounded with insulating material. Any device used to close the end of the tube must allow a free opening for equalization of pressure.

The sulphur should contain not over 0.02 per cent of impurities. Selenium is the impurity most likely to be present in quantities sufficient to affect the temperature of the boiling point.

The radiation shield is cylindrical and open at the lower end, and is provided with a conical portion at the top, to fit closely to the protecting tube of the thermometer. The cylindrical part is 1.5 to 2.5 cm larger in diameter than the protecting tube of the thermometer and at least 1 cm smaller in diameter than the inside of the boiling tube. The cylinder should extend at least 1.5 cm

THE INTERNATIONAL TEMPERATURE SCALE

TABLE 216 (*continued*).—Recommended Procedure for Calibration

beyond each end of the thermometer coil. There should be ample opening at the top of the cylindrical and below the conical portion to permit free circulation of vapor. The inner surface of the shield should be a poor reflector. The shield may be made of sheet metal, graphite, etc.

In standardizing a thermometer the sulphur is heated to boiling and the heating so regulated that the condensation line is at least 1 cm above the top of the insulating material. The thermometer with its radiation shield is inserted in the vapor, and when the line of condensation again reaches its former level simultaneous observations of resistance and barometric pressure are made. In all cases care should be taken to prove that the temperature is independent of vertical displacements of the thermometer and shield.

5. Silver and Gold

For standardizing a thermocouple, the metal to be used at its freezing point is contained in a crucible of pure graphite, refractory porcelain, or other material which will not react with the metal so as to contaminate it to an appreciable extent.

Silver must be protected from access of oxygen while heated.

The crucible and metal are placed in an electric furnace capable of heating the contents to a uniform temperature.

The metal is melted and brought to a uniform temperature a few degrees above its melting point, then allowed to cool slowly with the thermocouple immersed in it as described in the next paragraph.

The thermocouple, mounted in a porcelain tube with porcelain insulators separating the two wires, is immersed in the molten metal through a hole in the center of the crucible cover. The depth of immersion should be such that during the period of freezing the thermocouple can be lowered or raised at least 1 cm from its normal position without altering the indicated e.m.f. by as much as 1 microvolt. During freezing, the e.m.f. should remain constant within 1 microvolt for a period of at least five minutes.

As an alternative to displacing the couple, as a means of testing the absence of the influence of external conditions upon the observed temperature, both freezing and melting points may be observed and if these do not differ by more than 2 microvolts, the observed freezing point may be considered satisfactory.

TABLE 217.—The Standard Platinum Resistance Thermometer

The diameter of the wire should not be smaller than 0.05 or larger than 0.2 mm.

The platinum wire of the thermometer must be so mounted as to be subject to the minimum of mechanical constraint, so that dimensional changes accompanying changes of temperature may result in a minimum of mechanical strain being imposed upon the platinum.

The design of the thermometer should be such that the portion, the resistance of which is measured, shall consist only of platinum, and shall be at the uniform temperature which is to be measured. This may be accomplished by either of the accepted systems of current and potential, or compensating leads.

After completion, the thermometer should be annealed at a temperature of at least 660°.

THE INTERNATIONAL TEMPERATURE SCALE

TABLE 218.—The Standard Thermocouple

The platinum of the standard couple shall be of such purity that the ratio R_t/R_0 is initially not less than 1.390 for $t = 100°$. The alloy is to consist of 90 per cent platinum with 10 per cent rhodium. The completed thermocouple must develop an electromotive force, when one junction is at 0° and the other at the freezing point of gold, not less than 10,200 nor more than 10,400 international microvolts. The diameter of the wires used for standard thermocouples should lie between the values 0.35 and 0.65 mm.

The freezing point of antimony, specified for the standardization of the thermocouple, lies within the range of 0° to 660° where the international scale is fixed by the indications of the standard resistance thermometer, and the numerical value of this temperature is therefore to be determined with the resistance thermometer. In the appendix the result of such determinations is given as 630.5°, but the temperature of any particular lot of antimony which is to be used for standardizing the thermocouple is to be determined with a standard resistance thermometer.

The procedure to be followed in using the freezing point of antimony as a fixed temperature is substantially the same as that specified for silver. Antimony has a marked tendency to undercool before freezing. The undercooling will not be excessive if the metal is heated only a few degrees above its melting point and if the liquid metal is stirred. During freezing the temperature should remain constant within 0.1° for a period of at least five minutes.

TABLE 219.—Secondary Calibration Points

These points and their temperatures on the international scale are listed below. The temperatures correspond to a pressure of one standard atmosphere. The formulas for variation of vapor pressure with temperature are for the range from 680 to 780 mm.

	°C
Boiling hydrogen $t_p = t_{760} + 0.0044\,(p - 760)$	-252.7_5
Equilibrium between solid and gaseous carbon dioxide $t_p = t_{760} + 0.1443\,(t_p + 273.2)\log_{10}(p/760)$	−78.5
Freezing mercury	−38.87
Transition of sodium sulphate	32.38
Condensing naphthalene vapor $t_p = t_{760} + 0.208\,(t_p + 273.2)\log_{10}(p/760)$	217.96
Freezing tin	231.85
Condensing benzophenone vapor $t_p = t_{760} + 0.194\,(t_p + 273.2)\log_{10}(p/760)$	305.9
Freezing cadmium	320.9
Freezing lead	327.3
Freezing zinc	419.45
Freezing antimony	630.5
Freezing copper in a reducing atmosphere	1,083
Freezing palladium	1,553
Melting tungsten	3,400

Isopentane	−159.6	f*	Li_2SO_4	1202.	m †
Carbon dioxide	−111.6	f	Nickel	1455.	m, f
Toluene	−95.1	f	Cobalt	1490.	m, f
Ethyl acetate	−83.6	f	$CaAl_2Si_2O_8$	1555.	m
Chloroform	−63.5	f	Platinum	1755.	m
Carbon tetrachloride	−22.9	f			

* f, freezing. † m, melting.

DIRECTIONS FOR USE OF STANDARD THERMOELEMENT CALIBRATIONS

Deviation curves.—Standard tables such as are given on pages 245-247 have no absolute significance; they are reference curves that, while representing fairly well the e.m.f. functions for certain couples, are intended for use with an appropriate deviation curve. The correction curve is determined for each element by calibration at several fixed points—preferably three or more—given in the tables. It is constructed by plotting ΔE as ordinate ($\Delta E = E$ observed minus E standard) against E_{obs}. In order to obtain the temperatures corresponding to the measured e.m.f., the appropriate value of ΔE (obtained from its deviation curve by inspection) is subtracted algebraically from the observed value of E before the latter is converted into degrees by means of the table. The required accuracy may be secured by plotting the deviation curve on a small scale; coordinate paper 20 by 20 cm is ample. There need be no fear of error with this method even with deviations of several hundred μv, especially if sufficient calibration points are taken.

Fixed-junction correction.—Thermocouples have two junctions. The " business end " is usually called the hot junction, and the other, the cold junction.

The calibration tables are made on the assumption that the fixed junction is maintained at 0° C. The standard method is to use a vacuum-jacketed flask filled with ice into which is inserted the junction protected by a glass tube closed at one end and partly filled with kerosene. If it is not feasible to have the fixed junction at 0°, a fixed-junction correction must be applied. This correction, in general, is not equal to the temperature of the fixed junction and depends on both the temperature T_0 of the fixed junction and the temperature T of the variable junction. It may be applied by either of the following two methods.

(1) The e.m.f. corresponding to T_0 may be added directly to the e.m.f. $E_{T\text{-}T_0}$ and the resultant e.m.f. E_T, converted into degrees by means of the proper table (Tables 221-225). Thus if a platinum-platinrhodium couple gives a reading of 6000μv (microvolts), T_0 being 50°, the value of E_{T_0}, according to Table 221, is 298μv which added to 6000 gives 6298 as the value of E_T, which by referring to the table corresponds to $T = 703.6°$. This method of correction is mathematically exact. (2) Multiply the fixed junction temperature by a factor, $f = (dE/dt)_0/(dE/dt)$, the ratio of the mean e.m.f. temperature gradient between 0° and t_f to the gradient at t, and add the product to t', the uncorrected temperature, or $t = t' + ft_f$. The e.m.f. temperature gradients may be obtained by taking the reciprocals of the numbers corresponding in successive vertical difference of the numbers in the vertical columns.

TABLE 221.—Standard Calibration Curve for Pt—PtRh (10% Rh) Thermoelement

Giving the temperature for every 100 microvolts. For use in conjunction with a deviation curve determined by calibration of the particular element at some of the following fixed points:

Water	boiling-pt.	100.0	643mv	Silver	melting-pt.	960.2	9111mv.
Naphthalene	" "	217.95	1585	Gold	" "	1062.6	10296
Tin	melting-pt.	231.9	1706	Copper	" "	1082.8	10534
Benzophenone	boiling-pt.	305.9	2365	Li_2SiO_3	" "	1201.	11941
Cadmium	melting-pt.	320.9	2503	Diopside	" "	1391.5	14230
Zinc	" "	419.4	3430	Nickel	" "	1452.6	14973
Sulphur	boiling-pt.	444.55	3672				
Antimony	melting-pt.	630.0	5530	Palladium	" "	1549.5	16144
Aluminum	" "	658.7	5827	Platinum	" "	1755.	18608

E micro-volts.	0	1000.	2000.	3000.	4000.	5000.	6000.	7000.	8000.	9000.	E micro-volts.
	Temperatures, °C.										
0.	0.0	147.1	265.4	374.3	478.1	578.3	675.3	769.5	861.1	950.4	0.
100.	17.8	159.7	276.6	384.9	488.3	588.1	684.8	778.8	870.1	959.2	100.
200.	34.5	172.1	287.7	395.4	498.4	597.9	694.3	788.0	879.1	968.0	200.
300.	50.3	184.3	298.7	405.9	508.5	607.7	703.8	797.2	888.1	976.7	300.
400.	65.4	196.3	309.7	416.3	518.6	617.4	713.3	806.4	897.1	985.4	400.
500.	80.0	208.1	320.6	426.7	528.6	627.1	722.7	815.6	906.1	994.1	500.
600.	94.1	219.7	331.5	437.1	538.6	636.8	732.1	824.7	915.0	1002.8	600.
700.	107.8	231.2	342.3	447.4	548.6	646.5	741.5	833.8	923.9	1011.5	700.
800.	121.2	242.7	353.0	457.7	558.5	656.1	750.9	842.9	932.8	1020.1	800.
900.	134.3	254.1	363.7	467.9	568.4	665.7	760.2	852.0	941.6	1028.7	900.
1000.	147.1	265.4	374.3	478.1	578.3	675.3	769.5	861.1	950.4	1037.3	1000.

E micro-volts.	10000.	11000.	12000.	13000.	14000.	15000.	16000.	17000.	18000.	E micro-volts.
	Temperatures, °C.									
0.	1037.3	1122.2	1205.9	1289.3	1372.4	1454.8	1537.5	1620.9	1704.3	0.
100.	1045.9	1130.6	1214.2	1297.7	1380.7	1463.0	1545.8	1629.2	1712.6	100.
200.	1054.4	1139.0	1222.6	1306.0	1389.0	1471.2	1554.1	1637.6	1721.0	200.
300.	1062.9	1147.4	1230.9	1314.3	1397.3	1479.4	1562.4	1645.9	1729.3	300.
400.	1071.4	1155.8	1239.3	1322.6	1405.6	1487.7	1570.8	1654.3	1737.7	400.
500.	1079.9	1164.2	1247.6	1330.9	1413.8	1496.0	1579.1	1662.6	1746.0	500.
600.	1088.4	1172.5	1255.9	1339.2	1422.0	1504.3	1587.5	1670.9	1754.3	600.
700.	1096.9	1180.9	1264.3	1347.5	1430.2	1512.6	1595.8	1679.3		700.
800.	1105.4	1189.2	1272.6	1355.8	1438.4	1520.9	1604.2	1687.6		800.
900.	1113.8	1197.6	1281.0	1364.1	1446.6	1529.2	1612.5	1696.0		900.
1000.	1122.2	1205.9	1289.3	1372.4	1454.8	1537.5	1620.9	1704.3		1000.

TABLE 222.—Standard Calibration Curve for Copper—Constantan Thermoelement

For use in conjunction with a deviation curve determined by the calibration of the particular element at some of the following fixed points:

Water, boiling-point, 100°, 4276 microvolts; Naphthalene, boiling-point, 217.95, 10248 mv.; Tin, melting-point, 231.9, 11009 mv.; Benzophenone, boiling-point, 305.9, 15203 mv.; Cadmium, melting-point, 320.9, 16083 mv.

E. micro-volts.	0	1000.	2000.	3000.	4000.	5000.	6000.	7000.	8000.	9000.	E micro-volts.
	Temperatures, °C.										
0.	0.00	25.27	49.20	72.08	94.07	115.31	135.91	155.95	175.50	194.62	0.
100.	2.60	27.72	51.53	74.31	96.23	117.40	137.94	157.92	177.43	196.51	100.
200.	5.17	30.15	53.85	76.54	98.38	119.48	139.96	159.89	179.36	198.40	200.
300.	7.73	32.57	56.16	78.76	100.52	121.56	141.98	161.86	181.28	200.28	300.
400.	10.28	34.98	58.46	80.97	102.66	123.63	143.99	163.82	183.20	202.16	400.
500.	12.81	37.38	60.76	83.17	104.79	125.69	146.00	165.78	185.11	204.04	500.
600.	15.33	39.77	63.04	85.37	106.91	127.75	148.00	167.73	187.02	205.91	600.
700.	17.83	42.15	65.31	87.56	109.02	129.80	150.00	169.68	188.93	207.78	700.
800.	20.32	44.51	67.58	89.74	111.12	131.84	151.99	171.62	190.83	209.64	800.
900.	22.80	46.86	69.83	91.91	113.22	133.88	153.97	173.56	192.73	211.50	900.
1000.	25.27	49.20	72.08	94.07	115.31	135.91	155.95	175.50	194.62	213.36	1000

E micro-volts.	10000.	11000.	12000.	13000.	14000.	15000.	16000.	17000.	18000.	E micro-volts.
	Temperatures, °C.									
0.	213.36	231.74	249.82	267.60	285.13	302.42	319.49	336.36	353.09	0.
100.	215.21	233.56	251.61	269.36	286.87	304.14	321.19	338.04		100.
200.	217.06	235.38	253.40	271.12	288.61	305.85	322.88	339.72		200.
300.	218.91	237.20	255.18	272.88	290.35	307.56	324.57	341.40		300.
400.	220.75	239.01	256.96	274.64	292.08	309.27	326.26	343.07		400.
500.	222.59	240.82	258.74	276.40	293.81	310.98	327.95	344.74		500.
600.	224.43	242.63	260.52	278.15	295.54	312.69	329.64	346.41		600.
700.	226.26	244.43	262.29	279.90	297.26	314.39	331.32	348.08		700.
800.	228.09	246.23	264.06	281.65	298.98	316.09	333.00	349.75		800.
900.	229.92	248.03	265.83	283.39	300.70	317.79	334.68	351.42		900.
1000.	231.74	249.82	267.60	285.13	302.42	319.49	336.36	353.09		1000.

Cf. Day and Sosman, Am. Jour. Sci. 29, p. 93, 32, p. 517; *ibid.* R. B. Sosman, 30, p. 1.

TABLE 223.—Standard Calibration Curve for Copper—Constantan Thermoelement, Temperatures Below 0°C

E μv	−5000	−4000	−3000	−2000	−1000	0
0	−169.14	−124.46	− 87.86	−55.81	−26.82	0
	5.20	4.01	3.42	3.05	2.79	2.60
100	−174.34	−128.47	− 91.28	−58.86	−29.61	− 2.60
	5.40	4.09	3.46	3.08	2.81	2.62
200	−179.74	−132.56	− 94.74	−61.94	−32.42	− 5.22
	5.64	4.18	3.51	3.11	2.84	2.63
300	−185.38	−136.74	− 98.25	−65.05	−35.26	− 7.85
	5.89	4.28	3.57	3.15	2.86	2.65
400	−191.27	−141.02	−101.82	−68.20	−38.12	−10.50
	6.17	4.39	3.63	3.19	2.89	2.67
500	−197.44	−145.41	−105.45	−71.39	−41.01	−13.17
	6.51	4.50	3.68	3.22	2.90	2.69
600	−203.95	−149.91	−109.13	−74.61	−43.91	−15.86
	6.97	4.61	3.74	3.26	2.93	2.71
700	−210.92	−154.52	−112.87	−77.87	−46.84	−18.57
	7.55	4.73	3.80	3.29	2.96	2.73
800	−218.47	−159.25	−116.67	−81.16	−49.80	−21.30
		4.87	3.86	3.33	2.99	2.75
900		−164.12	−120.53	−84.49	−52.79	−24.05
		5.02	3.93	3.37	3.02	2.77
1000		−169.14	−124.46	−87.86	−55.81	−26.82

TABLE 224.—Melting Points of Some Purified Salts, 400-1300°C

(Roberts, some new standard melting points at high temperatures, Phys. Rev., 2d ser., 23, 386, 1924, which see for technique of their use.)

Potassium dichromate	397.5°C	Sodium chloride	800.4°C
45 KCl + 55 Na_2SO_4 by wt.	517.1	Sodium sulphate	884.7
30.5 NaCl + 69.5 Na_2SO_4 by wt.	627.0	Potassium sulphate *	1069.1
Potassium chloride	770.3	Dicalcium borate ($Ca_2B_2O_5$)	1304

* Potassium sulphate has sharp inversion point at 583° ± 1.

Table 225

STANDARD CALIBRATION CURVE FOR CHROMEL-ALUMEL THERMOELEMENT *

E mv	−0	0	10	20	30	40
0	0.0	0.0	250.1	490.5	733.8	991.3
	12.7	12.6	13.0	11.9	12.5	13.5
0.5	− 12.7	12.6	263.1	502.4	746.3	1004.8
	13.1	12.4	12.9	12.0	12.5	13.6
1.0	− 25.8	25.0	276.0	514.4	758.8	1018.4
	13.4	12.3	12.7	12.0	12.5	13.8
1.5	− 39.2	37.3	288.7	526.4	771.3	1032.2
	13.8	12.2	12.5	12.0	12.6	13.8
2.0	− 53.0	49.5	301.2	538.4	783.9	1046.0
	14.4	12.2	12.3	12.0	12.6	13.9
2.5	− 67.4	61.7	313.5	550.4	796.5	1059.9
	15.0	12.1	12.1	12.0	12.7	14.1
3.0	− 82.4	73.8	325.6	562.4	809.2	1074.0
	15.8	12.1	11.9	12.1	12.7	14.1
3.5	− 98.2	85.9	337.5	574.5	821.9	1088.1
	16.8	12.2	11.6	12.1	12.7	14.2
4.0	−115.0	98.1	349.1	586.6	834.6	1102.3
	18.1	12.2	11.5	12.1	12.8	14.4
4.5	−133.1	110.3	360.6	598.7	847.4	1116.7
	20.1	12.4	11.5	12.1	12.8	14.5
5.0	−153.2	122.7	372.1	610.8	860.2	1131.2
	22.8	12.5	11.7	12.2	12.9	14.5
5.5	−176.0	135.2	383.8	623.0	873.1	1145.7
	28.5	12.6	11.8	12.2	12.9	14.6
6.0	−204.5	147.8	395.6	635.2	886.0	1160.3
		12.6	11.8	12.2	13.0	14.7
6.5		160.4	407.4	647.4	899.0	1175.0
		12.7	11.8	12.3	13.0	14.8
7.0		173.1	419.2	659.7	912.0	1189.8
		12.7	11.8	12.3	13.1	14.8
7.5		185.8	431.0	672.0	925.1	1204.6
		12.8	11.9	12.3	13.1	15.0
8.0		198.6	442.9	684.3	938.2	(1220.0)
		12.8	11.9	12.3	13.2	15.0
8.5		211.4	454.8	696.6	951.4	(1235.0)
		12.9	11.9	12.4	13.2	16.0
9.0		224.3	466.7	709.0	964.6	(1251.0)
		12.9	11.9	12.4	13.3	16.0
9.5		237.2	478.6	721.4	977.9	(1267.0)
		12.9	11.9	12.4	13.4	16.0
10.0		250.1	490.5	733.8	991.3	(1283.0)

* Standard calibration curve for chromel-alumel (Hoskins) thermocouple giving the temperature and temperature differences for every 0.5 millivolt. Fixed junction is at 0°. For use in conjunction with a deviation curve determined by calibration of the particular couple at some of the following fixed points:

	Degrees C	Milli-volts mv		Degrees C	Milli-volts mv
S, boiling point	444.5	18.07	Au, melting point	1063.0	42.60
Sb, melting point	630.0	25.79	Cu (in air), melting point	1065.0	42.68
Al, melting point	660.0	27.00	Cu (pure), melting point	1082.8	43.31
Ag, melting point	960.2	38.83			

TABLE 226

OPTICAL PYROMETRY

(The following discussion is abbreviated from Dushman, Rev. Mod. Phys., 2, 387, 1930.)

Data on various substances are now available by which accurate determinations may be made of the temperature of an emitting surface. For a comprehensive review see Lax and Pirani, Handb. Phys., 19, 1-45; 21, 190-272, Julius Springer, Berlin, 1929. Data on total radiation from various bodies have been summarized by Coblentz (I.C.T. 5, 238-245, 1929).

Undoubtedly the most accurate method consists in determining the brilliancy (candles/cm^2). The temperature coefficient $(dB/B)/(dT/T)$ where $B=$ brightness in international candles/cm^2, for W varies from 22.75 at 1000° K. to 8.45 at 3000° K. (Jones, Langmuir, Gen. Elec. Rev., 30, 310, 354, 408, 1927). With the exception of electron emission and the rate of evaporation, the candlepower shows the greatest temperature variation.

While the values of B as a function of T are available for several substances, a fair approximation is possible to the true T of a substance for which the average luminous emissivity is unknown by the following methods. (Average luminous emissivity means the ratio of the total normal brightness to that of a black-body at the same T. For W this value is from 0.464, $T=1000°$ K. to 0.440, $T=3000°$ K., Forsythe, Worthing, Astrophys. Journ., 61, 126, 1925).

With a photometer determine the temperature T_c at which substance emits light of the *same color* as a black-body—a value higher than the true temperature. The following table is due to Worthing-Forsythe:

T_c (tungsten)	True T	$(T_c-T)/T$	T_s (tungsten)
1006° K.	1000° K.	0.006	966° K.
1517	1500	.011	1420
2033	2000	.0165	1857
2557	2500	.023	2274
3094	3000	.031	2673

The brightness may be compared with a standard lamp for a given wave length, usually 0.665μ. The temperature found is called the brightness temperature, T_s, lower than the true temperature, increasingly so with decrease in e_λ, the emissivity for this wave length, and increasing with the temperature. Thus for *w*, e_λ for $\lambda=0.665\mu$ varies from 0.456, $T=1000°$ K. to 0.415, $T=3000°$ K. and the observed values T_s are given in the preceding table. From these determinations of T_c and T_s fairly approximate values of T may be deduced.

It is possible to determine the actual value of e_λ by methods described by both Langmuir, Worthing and Forsythe, then calculate T, the true temperature from optical pyrometer measurements of T. See Forsythe, Journ. Opt. Soc. Amer., 16, 307, 1928; Journ. Amer. Ceram. Soc., 12, 780, 1929; Foote, Fairchild, Symposium on Pyrometer, Amer. Inst. Mining and Metallurg. Eng., 338, 324, 1920; also loc. cit., p. 291, 367, 285.

At temperatures below 1100-1200° K. optical methods become impractical, and radiation in watts radiated per unit area or resistance must be used. Data on energy radiated as a function of the temperature have been summarized by Lax and Pirani, Handb. Phys., 21, 236-240, for W, Mo, Ta, Pr, Os, Au, Ni, Fe, C, Ag, Cu, and Zr.

TABLE 227.—Correction for Temperature of Emergent Mercurial Thermometer Thread

When the temperature of a portion of a thermometer stem with its mercury thread differs much from that of the bulb, a correction is necessary to the observed temperature unless the instrument has been calibrated for the experimental conditions. This stem correction is proportional to $n\beta(T-t)$, where n is the number of degrees in the exposed stem, β the apparent coefficient of expansion of mercury in the glass, T the measured temperature, and t the mean temperature of the exposed stem. For temperatures up to 100° C, the value of β is for Jena 16^{III} or Greiner and Friedrich resistance glass, 0.000159, for Jena 59^{III}, 0.000164, and when of unknown composition it is best to use a value of about 0.000155. The formula requires a knowledge of the temperature of the emergent stem. This may be approximated in one of three ways: (1) by a "fadenthermometer" (see Buckingham, Bulletin Bureau of Standards, 8, p. 239, 1912); (2) by exploring the temperature distribution of the stem and calculating its mean temperature; and (3) by suspending along the side of, or attaching to the stem, a single thermometer. Table 228 is taken from the Smithsonian Meteorological Tables.

TABLE 228.—Stem Correction for Centigrade Thermometers

Values of $0.000155n(T-t)$.

n	(T−t).							
	10°	20°	30°	40°	50°	60°	70°	80°
10° C	0.02	0.03	0.05	0.06	0.08	0.09	0.11	0.12
20	0.03	0.06	0.09	0.12	0.16	0.19	0.22	0.25
30	0.05	0.09	0.14	0.19	0.23	0.28	0.33	0.37
40	0.06	0.12	0.19	0.25	0.31	0.37	0.43	0.50
50	0.08	0.16	0.23	0.31	0.39	0.46	0.54	0.62
60	0.09	0.19	0.28	0.37	0.46	0.56	0.65	0.74
70	0.11	0.22	0.33	0.43	0.54	0.65	0.76	0.87
80	0.12	0.25	0.37	0.50	0.62	0.74	0.87	0.99
90	0.14	0.28	0.42	0.56	0.70	0.84	0.98	1.12
100	0.16	0.31	0.46	0.62	0.78	0.93	1.08	1.24

TABLE 229.—Reduction of Gas Thermometers to Thermodynamic Scale

The final standard scale is Kelvin's thermodynamic scale, independent of the properties of any substance, a scale resulting from the use of a gas thermometer using a perfect gas. A discussion of this is given by Buckingham, Bur. Standards Bull., 3, 237, 1907: "The thermodynamic correction of the centigrade constant-pressure scale at the given temperature is very nearly proportional to the constant pressure at which the gas is kept" and "the thermodynamic correction to the centigrade constant-volume scale is approximately proportional to the initial pressure at the ice point." These two rules are very convenient, since from the corrections for any one pressure, one can calculate approximately those for the same gas at any other pressure.

The highest temperature possible is limited by the container for the gas. Day and Sosman carried a platinum-rhodium gas thermometer up to the melting point of palladium. For most work, however, the region of the gas thermometer should be considered as ending at about 1000° C (1273° K.).

Note: All corrections in the following table are to be added *algebraically.*

273.1° C (ice point)

For a discussion of the various values and for the corrections of the various gas thermometers to the thermodynamic scale see Buckingham, Bull. Bureau Standards, 3, p. 237, 1907.

Scale Corrections for Gas Thermometers.

Temp. °C	Constant pressure = 100 cm			Constant vol., p_0 = 100 cm, t_0 = 0°C		
	He	H	N	He	H	N
− 240°	—	+1.0	—	+0.02	+0.18	—
− 200	+0.13	+ .26	—	+ .01	+ .06	—
− 100	+ .04	+ .03	+0.40	.000	+ .010	+0.06
− 50	+ .012	+ .02	+ .12	.000	+ .004	+ .02
+ 25	− .003	− .003	− .020	.000	.000	− .006
+ 50	− .003	− .003	− .025	.000	.000	− .006
+ 75	− .003	− .003	− .017	.000	.000	− .004
+ 150	+ .007	+ .01	+ .04	+ .000	+ .001	+ .01
+ 200	+ .01	+ .02	+ .11	.000	+ .002	+ .04
+ 450	+ .1	+0.04	+ .5	0.00	+0.01	+ .2
+1000	+0.3	—	+1.7	—	—	+ .7
+1500	—	—	+3.	—	—	+1.3

TABLE 230
PRACTICAL THERMOELECTRIC SCALES
(Comparisons)

(Adapted from Roeser, Bur. Standards Res. Paper 99, 1929, which see for details of use.)

Prior to the adoption of the International Temperature Scale, the Pt-Pt10% Rh thermocouple was almost universally used for scales 450° to 1100°C, and defining equations were quadratic or cubic depending upon the number of calibration points.

The scale based on the work of Holborn and Day was calibrated at the freezing point of Zn (419.0°C), Sb (630.6°C) and Cu (1084.1°C) and a quadratic equation, $E = a + vt + ct^2$, for interpolation. This was almost universally used from 1900–1909. Work of Waidner, Burgess, 1909, and Day, Sosman, 1910–1912, necessitated a readjustment. In 1912 the Bureau of Standards redefined its scale, assigning values determined with the resistance thermometer to the Zn and Sb points, while the freezing point of Cu was taken as 1083.0°C. This 1912 scale, used from 1912–1916, will be called the Zn,Sb,Cu temperature scale.

A scale proposed by Sosman and revised by Adams (Journ. Amer. Chem. Soc., 36, 65, 1914) was realized by using a standard reference table, giving the average *t*,e.m.f. relation for thermocouple used by Day and Sosman. A deviation curve, determined by any other couple by calibration at several points would be plotted relating the difference between observed e.m.f. and the e.m.f. from the reference table against the obs. e.m.f. of the couple. This scale, although very convenient, is not completely defined and no comparison is made here.

In 1916, the Physikalische-Technische Reichsanstalt adopted a scale with the couple calibrated at the Cd point (320.9°C), Sb (630°C), An (1063°C) and Pd (1557°C). No comparison will be made here.

A scale adopted by the Bureau of Standards in 1916 was defined by calibration at the Zn and Al points with a Cu point (1083.0°C). This was used from 1916–1926 and is here designated the Zn,Al,Cu scale.

The scale adopted by the P.T.R. and the Bureau of Standards in 1924 was calibrated at Zn and Sb points (determined by resistance thermometer) and the Ag point (960.5°C) and the Au point (1063.0°C). It will be designated the Zn,Sb,Ag,Au scale.

The 1927 7th Annual Conference of Weights and Measures (31 nations) unanimously adopted what is between 660° and 1063°C the Zn,Sb,Ag,Cu scale with the Zn point omitted. The table below shows a comparison of the various scales. The following values for the freezing points were used:

Zn 419.47°C	Al 659.23°C	Au	1063.0°C
Sb 630.52°C	Ag 960.5°C	Cu (reducing atm.[e])	1083.0°C

Table 231 gives the corresponding difference of temperature.

Comparison of *t*°C—e.m.f. relations with International Temperature Scale. (Comparisons with two thermo-couples are given.)

Temperature (°C)	E.m.f. in microvolts for temperature scales, Thermocouple A				E.m.f. in microvolts for temperature scales, Thermocouple B			
	Zn, Sb, and Cu	Zn, Al, and Cu	Zn, Sb, Ag, and Au	International temperature scale	Zn, Sb, and Cu	Zn, Al, and Cu	Zn, Sb, Ag, and Au	International temperature scale
419.47	3438.2	3438.2	3438.2	3447.5	3435.6	3435.6	3435.6	3444.7
450	3732.9	3732.8	3733.4	3740.5	3729.8	3729.6	3730.2	3737.2
500	4222.6	4222.2	4223.3	4227.6	4218.6	4218.2	4219.3	4223.5
550	4720.9	4720.4	4721.6	4723.7	4716	4715.4	4716.6	4718.7
600	5227.9	5227.2	5228.2	5228.8	5221.9	5221.2	5222.4	5222.9
630.52	5541.6	5540.9	5541.6	5541.6	5535	5534.2	5535	5535
650	5743.5	5742.8	5743.3	5743	5736.5	5735.7	5736.3	5736
659.23	5839.7	5838.9	5839.3	5838.9	5832.4	5831.6	5832.1	5831.6
700	6267.8	6267	6267	6266.1	6259.7	6258.8	6258.8	6258
750	6800.8	6800	6799.3	6798.3	6791.5	6790.6	6790	6789
800	7342.5	7341.7	7340.3	7339.4	7331.9	7331	7329.8	7328.9
850	7892.8	7892.1	7890.2	7889.6	7880.9	7880.1	7878.4	7877.7
900	8451.8	8451.2	8449.1	8448.8	8438.5	8437.8	8435.8	8435.5
950	9019.5	9019	9017	9016.9	9004.8	9004.2	9002.3	9002.2
960.50	9139.8	9139.3	9137.4	9137.4	9124.8	9124.2	9122.4	9122.4
1000	9595.8	9595.5	9594	9594.1	9579.6	9579.2	9577.8	9577.9
1050	10180.8	10180.7	10180.3	10180.3	10163	10162.8	10162.5	10162.5
1063	10334.4	10334.3	10334.2	10334.2	10316.1	10316	10316	10316
1083	10571.7	10571.7	10572.3	10572.1	10552.8	10552.8	10553.4	10553.3
1100	10774.5	10774.6	10775.8	10775.5	10755.1	10755.2	10756.4	10756.1

TABLE 231.—Temperature Differences between I.T.S. and various Older Scales

°C	I.T.S.-ZnSb-Cu	I.T.S.-ZnAl-Cu	I.T.S.-ZnSb-AgAu	°C	I.T.S.-ZnSb-Cu	I.T.S.-ZnAl-Cu	I.T.S.-ZnSb-AgAu	°C	I.T.S.-ZnSb-Cu	I.T.S.-ZnAl-Cu	I.T.S.-ZnSb-AgAu
600	−°.08	°.00	−°.04	900	−°.26	−°.21	−°.03	1050	−°.04	−°.03	°.00
700	− .16	− .08	− .08	950	− .23	− .18	− .01	1063	− .01	.00	.00
750	− .24	− .16	− .09	960.5	− .21	− .16	.00	1083	+ .04	+ .03	− .01
800	− .28	− .20	− .08	1000	− .15	− .12	.01	1100	+ .08	+ .08	− .03
850	− .29	− .22	− .06								

TABLE 232.—Conversion Factors for Units of Work

	Joules	Foot-pounds	Kilogram-meters	15° Calories	British thermal units	Kilowatt-hours
1 Joule.........=	1	0.7376†	0.1020†	0.2391	0.0009486	0.2778×10^{-6}
1 Foot-pound....=	1.356*	1	0.1383	0.3241*	0.001286*	0.3767×10^{-6}*
1 Kilogram-meter=	9.807*	7.234	1	2.345*	0.009302*	2.724×10^{-6}*
1 15° Calorie....=	4.183	3.085†	0.4267†	1	0.003965	1.162×10^{-6}
1 British thermal unit........=	1054.	777.5†	107.5†	251.9	1	0.0002928
1 Kilowatt-hour..=	3 600 000.	2 655 000.†	367 200.†	860 800.	3415.	1

The value used for g is the standard value, 980.665 cm. per sec. per sec. = 32.174 feet per sec. per sec.
* The values thus marked vary directly with "g."
† The values thus marked vary inversely with "g." For values of "g" see Tables 706–709.

TABLE 233.—Value of the English and American Horsepower (746 watts) in Local Foot-pounds and Kilogram-meters per Second at Various Altitudes and Latitudes

Altitude	Kilogram-meters per second					Foot-pounds per second				
	Latitude					Latitude				
	0°	30°	45°	60°	90°	0°	30°	45°	60°	90°
0 km	76.275	76.175	76.074	75.973	75.873	551.70	550.97	550.24	549.52	548.79
1.5 "	76.297	76.197	76.095	75.995	75.895	551.86	551.13	550.41	549.68	548.95
3 "	76.320	76.220	76.119	76.018	75.918	552.03	551.30	550.57	549.85	549.12

TABLE 234.—Nonflammable Liquids for Cryostats
(Taken from Kanolt, Bur. Standards Sci. Paper, 520, 1926.)

Liquid..............	CCl_4	$CHCl_3$	4*	C_2H_5Br	32	39*	No. 40
Freezing point....... °C	−23	−63	−81	−119	−139	−145	−150±

*Compositions: No. 4; CCl_4, 49.4%; $CHCl_3$, 50.6%.
No. 32; $CHCl_3$, 19.7%; C_2H_5Br, 44.9%; $C_2H_2Cl_2$, 13.8%; C_2HCl_3, 21.6%.
No. 39; $CHCl_3$, 14.5%; C_2H_5Br, 33.4%; $C_2H_2Cl_2$, 10.4%; C_2HCl_3, 16.4%; CH_2Cl_2, 25.3%.
No. 40; $CHCl_3$, 17.9%; C_2H_5Cl, 9.3%; C_2H_5Br, 40.7%; $C_2H_2Cl_2$, 125%; C_2HCl_3, 19.6%.

		−80°C	−90°	−100°	−110°	−120°	−130°	−140°	−145°	−150°
Viscosities in centipoises:	C_2H_5Br	1.81	2.25	2.89	3.86	5.6	...	...	...	...
	No. 32	...	3.03	4.57	7.4	13.7	29.3	81	...	...
	No. 34	1.97	2.57	3.69	5.6	10	22.3	85	242	1480
	No. 40	...	2.88	3.89	5.9	10.2	22.5	71	170	631

* Because of volatility and oxidation of some, these liquids should be kept in well stoppered bottles when not in use.

TABLE 235

MELTING AND BOILING POINTS OF THE CHEMICAL ELEMENTS

Element	Symbol and atomic no.	Melting point °C	Boiling point °C	Element	Symbol and atomic no.	Melting point °C	Boiling point °C
Aluminum	Al 13	659.7	1800	Molybdenum	Mo 42	2620	3700
Antimony	Sb 51	630.5	1380	Neodymium	Nd 60	840	
Argon	A 18	− 189.2	− 185.7	Neon	Ne 10	− 248.67	− 245.9
Arsenic	As 33	(820)	615.s	**Nickel**	Ni 28	1455	2900
Barium	Ba 56	850	1140	Nitrogen	N 7	− 209.86	− 195.81
Beryllium	Be 4	1350	(1500)	Osmium	Os 76	2700	(>5300)
Bismuth	Bi 83	271.3	1450	Oxygen	O 8	− 218.4	− 183
Boron	B 5	2300		Ozone	O_3	− 251.4	− 112
Bromine	Br 35	− 7.2	58.8	**Palladium**	Pd 46	1553	2200
Cadmium	Cd 48	320.9	766	Phosphorus	P 15	44.1	280
Calcium	Ca 20	810	1170	**Platinum**	Pt 78	1773.5	4300
Carbon	C 6	>3500	(4200)	Potassium	K 19	62.3	760
Cerium	Ce 58	640	1400	Praseodymium	Pr 59	940	
Cesium	Cs 55	26	670	Radium	Ra 88	960	1140
Chlorine	Cl 17	− 101.6	− 34.7	Radon	Rn 86	− 110	
Chromium	Cr 24	1615	2200	Rhenium	Re 75	(3000)	
Cobalt	Co 27	1480	3000	Rhodium	Rh 45	1985	>2500
Columbium	Cb 41	1950	2900	Rubidium	Rb 37	38.5	700
Copper	Cu 29	1083	2300	Ruthenium	Ru 44	2450	>2700
Dysprosium	Dy 66			Samarium	Sm 62	>1300	
Erbium	Er 68			Scandium	Sc 21	1200	(2400)
Europium	Eu 63			Selenium	Se 34	220	688
Fluorine	F 9	− 223	− 187	Silicon	Si 14	1420	2600
Gadolinium	Gd 64			**Silver**	Ag 47	960.5	1950
Gallium	Ga 31	29.7	>1600	Sodium	Na 11	97.5	880
Germanium	Ge 32	958.5	(2700)	Strontium	Sr 38	800	1150
Gold	Au 79	1063	2600	Sulphur	S 16	113–119	444.6
Hafnium	Hf 72	(1700)	(>3200)	Tantalum	Ta 73	2850	(>4100)
Helium	He 2	<−272	− 268.94	Tellurium	Te 52	452	1390
Holmium	Ho 67			Terbium	Tb 65		
Hydrogen	H 1	− 259.14	− 252.8	Thallium	Tl 81	303.5	1650
Indium	In 49	155	>1450	Thorium	Th 90	1845	>3000
Iodine	I 53	113.5	184.35	Thulium	Tm 69		
Iridium	Ir 77	2350	(>4800)	**Tin**	Sn 50	231.89	2260
Iron	Fe 26	1535	3000	Titanium	Ti 22	1800	(>3000)
Krypton	Kr 36	− 169	− 151.8	Tungsten	W 74	3370	5900
Lanthanum	La 57	826	1800	Uranium	U 92	<1850	
Lead	Pb 82	327.4	1620	Vanadium	V 23	1710	(3000)
Lithium	Li 3	186	>1200	Xenon	Xe 54	− 140	− 109.1
Lutecium	Lu 71			Ytterbium	Yb 70		
Magnesium	Mg 12	651	1100	Yttrium	Y 39	1490	(2500)
Manganese	Mn 25	1260	1900	**Zinc**	Zn 30	419.47	907
Mercury	Hg 80	− 38.87	356.90	Zirconium	Zr 40	1900	>2900

(Metals in heavy type are often used as standard melting points.)

TABLE 236.—Effect of Pressure on Melting Point

Substance.	Melting point at 1 kg/sq. cm	Highest experimental pressure: kg/sq. cm	dt/dp at 1 kg/sq. cm	Δt (observed) for 1000 kg/sq. cm	Reference
Hg	−38.85	12,000	0.00511	5.1 *	1
K	59.7	2,800	0.0136	13.8	2
Na	97.62	12,000	0.00860	+12.3†	4
Bi	271.0	12,000	−0.00342	−3.5†	4
Sn	231.9	2,000	0.00317	3.17	3
Bi	270.9	2,000	−0.00344	−3.44	3
Cd	320.9	2,000	0.00609	6.09	3
Pb	327.4	2,000	0.00777	7.77	3

* Δt (observed) for 10,000 kg/sq. cm is 50.8°.

† Na melts at 177.5° at 12,000 kg/cm²; K at 179.6°; Bi at 218.3°; Pb at 644°. Luckey obtains melting point for tungsten as follows: 1 atme, 3623° K; 8, 3594; 18, 3572; 28, 3564. Phys. Rev. 1917.

References: (1) P. W. Bridgman, Proc. Am. Acad. 47, pp. 391–96, 416–19, 1911; (2) G. Tammann, Kristallisieren und Schmelzen, Leipzig, 1903, pp. 98–99; (3) J. Johnston and L. H. Adams, Am. J. Sci. 31, p. 516, 1911; (4) P. W. Bridgman, Phys. Rev. 6, 1, 1915.

A large number of organic substances, selected on account of their low melting points, have also been investigated: by Tammann, *loc. cit.;* G. A. Hulett, Z. physik. Chem. 28, p. 629, 1899; F. Körber, *ibid.*, 82, p. 45, 1913; E. A. Block, *ibid.*, 82, p. 403, 1913; Bridgman, Phys. Rev. 3, 126, 1914; Pr. Am. Acad. 51, 55, 1915; 51, 581, 1916; 52, 57, 1916; 52, 91, 1916. The results for water are given in the following table.

TABLE 237.—Effect of Pressure on Freezing Point of Water *

Pressure: † kg/sq. cm	Freezing point.	Phases in Equilibrium.
1	0.0	Ice I — liquid.
1,000	−8.8	Ice I — liquid.
2,000	−20.15	Ice I — liquid.
2,115	−22.0	Ice I — ice III — liquid (triple point).
3,000	−18.40	Ice III — liquid.
3,530	−17 0	Ice III — ice V — liquid (triple point).
4,000	−13.7	Ice V — liquid.
6,000	− 1.6	Ice V — liquid.
6,380	+ 0.16	Ice V — ice VI — liquid (triple point).
8,000	12.8	Ice VI — liquid.
12,000	37.9	Ice VI — liquid.
16,000	57.2	Ice VI — liquid.
20,000	73.6	Ice VI — liquid.

* P. W. Bridgman, Proc. Am. Acad. 47, pp. 441–558, 1912.

† 1 atm. = 1.033 kg/sq. cm.

TABLE 238.—Effect of Pressure on Boiling Point *

Metal.	Pressure.	° C	Metal.	Pressure.	° C	Metal.	Pressure.	° C
Bi	10.2 cm Hg.	1200	Ag	26.3 cm Hg.	1780	Pb	20.6 cm Hg.	1410
Bi	25.7 cm Hg.	1310	Cu	10.0 cm Hg.	1980	Pb	6.3 atme.	1870
Bi	6.3 atme.	1740	Cu	25.7 cm Hg.	2180	Pb	11.7 atme.	2100
Bi	11.7 atme.	1950	Sn	10.1 cm Hg.	1970	Zn	11.7 atme.	1230
Bi	16.5 atme.	2060	Sn	26.2 cm Hg.	2100	Zn	21.5 atme.	1280
Ag	10.3 cm Hg.	1660	Pb	10.5 cm Hg.	1315	Zn	53.0 atme.	1510

* Greenwood, Pr. Roy. Soc., p. 483, 1910.

Table 239

DENSITIES AND MELTING AND BOILING POINTS OF INORGANIC COMPOUNDS

Substance.	Chemical formula.	Density, about 20° C	Melting point C	Authority.	Boiling point C	Pressure mm	Authority.
Aluminum chloride	$AlCl_3$	—	190.	1	183.°	752	1
" nitrate	$Al(NO_3)_3 + 9H_2O$	—	72.8	2	134.*	—	—
" oxide	Al_2O_3	4.00	2050.	28	—	—	—
Ammonia	NH_3	—	−75.	3	−33.5	760	7
Ammonium nitrate	NH_4NO_3	1.72	165.	—	210.*	—	—
" sulphate	$(NH_4)_2SO_4$	1.77	140.	4	—	—	—
" phosphite	$NH_4H_2PO_3$	—	123.	5	150.*	—	—
Antimony trichloride	$SbCl_3$	3.06	73.	—	223.	760	—
" pentachloride	$SbCl_5$	2.35	3.	11	102.	68	14
Arsenic trichloride	$AsCl_3$	2.20	−18.	8	130.2	760	23
Arsenic hydride	AsH_3	—	−113.5	6	−54.8	760	6
Barium chloride	$BaCl_2$	3.86	960.	11	—	—	—
" nitrate	$Ba(NO_3)_2$	3.24	575.	24	—	—	—
" perchlorate	$Ba(ClO_4)_2$	—	505.	10	—	—	—
Bismuth trichloride	$BiCl_3$	4.56	232.5	—	440.	760	—
Boric acid	H_3BO_3	1.46	185.	—	—	—	—
" anhydride	B_2O_3	1.79	577.	—	—	—	—
Borax (sodium borate)	$Na_2B_4O_7$	2.36	741.	27	—	—	—
Cadmium chloride	$CdCl_2$	4.05	560.	25	900 ±	—	9
" nitrate	$Cd(NO_3)_2 + 4H_2O$	2.45	59.5	2	132.	760	4
Calcium chloride	$CaCl_2$	2.26	774.0	—	—	—	—
" chloride	$CaCl_2 + 6H_2O$	1.68	29.6	—	—	—	—
" nitrate	$Ca(NO_3)_2$	2.36	499.	24	—	—	—
" nitrate	$Ca(NO_3)_2 + 4H_2O$	1.82	42.3	26	132.*	—	—
" oxide	CaO	3.3	2570.	28	—	—	—
Carbon tetrachloride	CCl_4	1.59	−24.	22	76.7	760	23
" trichloride	C_2Cl_6	1.63	184.	—	—	—	—
" monoxide	CO	—	−207.	6	−190.	760	6
" dioxide	CO_2	1.56	−57.	3	−80.	subl.	—
" disulphide	CS_2	1.26	−110.	13	46.2	760	—
Chloric(per) acid	$HClO_4 + H_2O$	1.81	50.	15	—	—	—
Chlorine dioxide	ClO_2	—	−76.	3	9.9	731	21
Chrome alum	$KCr(SO_4)_2 + 12H_2O$	1.83	89.	16	—	—	—
" nitrate	$Cr_2(NO_3)_6 + 18H_2O$	—	37.	2	170.	760	2
Chromium oxide	Cr_2O_3	5.04	1990.	28	—	—	—
Cobalt sulphate	$CoSO_4$	3.53	97.	16	880.*	—	—
Cupric chloride	$CuCl_2$	3.05	498.	9	*	—	—
Cuprous chloride	Cu_2Cl_2	3.7	421.	—	1000 ±	760	9
Cupric nitrate	$Cu(NO_3)_2 + 3H_2O$	2.05	114.5	2	170.*	760	2
Hydrobromic acid	HBr	—	−86.7	3	−68.7	760	—
Hydrochloric acid	HCl	—	−111.3	17	−83.1	755	17
Hydrofluoric acid	HFl	0.99	−92.3	6	−36.7	755	17
Hydriodic acid	HI	—	−51.3	17	−35.7	760	—
Hydrogen peroxide	H_2O_2	1.5	−2.	18	80.2	47	20
" phosphide	PH_3	—	−132.5	6	—	—	—
" sulphide	H_2S	—	−86.	3	−62.	—	—
Iron chloride	$FeCl_3$	2.80	301.	—	—	—	—
" nitrate	$Fe(NO_3)_3 + 9H_2O$	1.68	47.2	2		—	—
" sulphate	$FeSO_4 + 7H_2O$	1.90	64.	16	—	—	—
Lead chloride	$PbCl_2$	5.8	500.	9	900 ±	760	—
" metaphosphate	$Pb(PO_3)_2$	—	800.	9	—	—	—
Magnesium chloride	$MgCl_2$	2.18	708.	9	—	—	—
" oxide	MgO	3.4	2800.	28	—	—	—
" nitrate	$Mg(NO_3)_2 + 6H_2O$	1.46	90.	2	143.	760	2
" sulphate	$MgSO_4 + 5H_2O$	1.68	150.	16	—	—	—
Manganese chloride	$MnCl_2 + 4H_2O$	2.01	87.5	19	106.	760	19
" nitrate	$Mn(NO_3)_2 + 6H_2O$	1.82	26.	2	129.	760	2
" sulphate	$MnSO_4 + 5H_2O$	2.09	54.	16	—	—	—
Mercurous chloride	Hg_2Cl_2	7.10	450 ±	—	—	—	—
Mercuric chloride	$HgCl_2$	5.42	282.	—	305.	—	—

(1) Friedel and Crafts; (2) Ordway; (3) Faraday; (4) Marchand; (5) Amat; (6) Olszweski; (7) Gibbs; (8) Baskerville; (9) Carnelly; (10) Carnelly and O'Shea; (11) Ruff; (13) Wroblewski and Olszewski; (14) Anschütz; (15) Roscoe; (16) Tilden; (17) Ladenburg; (18) Staedel; (19) Clarke, Const. of Nature; (20) Bruhl; (21) Schacherl; (22) Tammann; (23) Thorpe; (24) Ramsay; (25) Lorenz; (26) Morgan; (27) Day; (28) Kanolt. * Decomposes.

DENSITIES AND MELTING AND BOILING POINTS OF INORGANIC COMPOUNDS

Substance.	Chemical formula.	Density, about 20° C	Melting point C	Authority.	Boiling point C	Pressure mm	Authority.
Nickel carbonyl	NiC_4O_4	1.32	−25.	1	43.°	760	—
“ nitrate	$Ni(NO_3)_2 + 6H_2O$	2.05	56.7	2	136.7	760	2
“ oxide	NiO	6.69	—	—	—	—	—
“ sulphate	$NiSO_4 + 7H_2O$	1.98	99.	3	—	—	—
Nitric acid	HNO_3	1.52	−42.	4	86.	760	16
“ anhydride	N_2O_5	1.64	30.	5	48.	760	9
“ oxide *	NO	1.27	−167.	—	−153.	760	6
“ peroxide	N_2O_4	1.49	−9.6	8	21.6	760	—
Nitrous anhydride	N_2O_3	1.45	−111.	7	3.5	760	—
“ oxide	N_2O	—	−102.4	8	−89.8	760	8
Phosphoric acid (ortho)	H_3PO_4	1.88	40 ±	—	—	—	—
Phosphorous acid	H_3PO_3	1.65	72.	—	—	—	—
Phosphorus trichloride	PCl_3	1.61	−111.8	10	76.	760	19
“ oxychloride	$POCl_3$	1.68	+1.3	—	108.	760	—
“ disulphide	P_3S_6	—	297.	12	—	760	—
“ pentasulphide	P_2S_5	—	275.	13	522.	760	—
“ sesquisulphide	P_4S_3	2.00	168.	—	400.	760	—
“ trisulphide	P_2S_3	—	290 ±	14	490.	760	25
Potassium carbonate	K_2CO_3	2.29	909.	—	—	—	—
“ chlorate	$KClO_3$	2.34	357.	15	—	—	—
“ chromate	K_2CrO_4	2.72	975.	17	—	—	—
“ cyanide	KCN	1.52	red h't	—	—	—	—
“ perchlorate	$KClO_4$	2.52	610.	15	410. †	760	—
“ chloride	KCl	1.99	772.	—	1500.	760	—
“ nitrate	KNO_3	2.10	341.	—	400. †	—	—
“ acid phosphate	KH_2PO_4	2.34	96.	3	—	—	—
“ acid sulphate	$KHSO_4$	2.35	205.	—	dec.	—	—
Silver chloride	$AgCl$	5.56	451.	15	—	—	—
“ nitrate	$AgNO_3$	4.35	218.	—	dec.	—	—
“ perchlorate	$AgClO_4$	—	486.	18	—	—	—
“ phosphate	Ag_3PO_4	6.37	849.	15	—	—	—
“ metaphosphate	$AgPO_3$	—	482.	15	—	—	—
“ sulphate	Ag_2SO_4	5.45	655 ±	—	1085. †	—	—
Sodium chloride	$NaCl$	2.17	800.	11	1490.	760	—
“ hydroxide	$NaOH$	2.1	318.	27	—	—	—
“ nitrate	$NaNO_3$	2.26	315.	—	380. †	—	—
“ chlorate	$NaClO_3$	2.48	248.	28	†	—	—
“ perchlorate	$NaClO_4$	—	482.	18	—	—	—
“ carbonate	Na_2CO_3	2.48	852.	—	†	—	—
“ carbonate	$Na_2CO_3 + 10H_2O$	1.46	34.	3	—	—	—
“ phosphate	$Na_2HPO_4 + 12H_2O$	1.54	38.	—	—	—	—
“ metaphosphate	$NaPO_3$	2.48	617.	15	—	—	—
“ pyrophosphate	$Na_4P_2O_7$	2.45	970.	30	—	—	—
“ phosphite	$(H_2NaPO_3)_2 + 5H_2O$	—	42.	20	—	—	—
“ sulphate	Na_2SO_4	2.67	884.	11	—	—	—
“ sulphate	$Na_2SO_4 + 10H_2O$	1.46	32.38	17	—	—	—
“ hyposulphite	$Na_2S_2O_3 + 5H_2O$	1.73	48.16	—	†	—	—
Sulphur dioxide	SO_2	—	−76.	—	−10.	760	—
Sulphuric acid	H_2SO_4	1.83	10.4	21	338.	760	22
“ acid	$12H_2SO_4 + H_2O$	—	−0.5	22	—	—	—
“ acid	$H_2SO_4 + H_2O$	—	8.5	—	—	—	—
“ acid (pyro)	$H_2S_2O_7$	1.89	35.	22	†	—	—
Sulphur trioxide	SO_3	1.91	16.8	—	44.9	760	—
Tin, stannic chloride	$SnCl_4$	2.28	−33.	23	114.	760	19
“ stannous chloride	$SnCl_2$	—	250.	24	605.	760	—
Zinc chloride	$ZnCl_2$	2.91	365.	29	710.	760	—
“ chloride	$ZnCl_2 + 3H_2O$	—	6.5	26	—	—	—
“ nitrate	$Zn(NO_3)_2 + 6H_2O$	2.06	36.4	3	131.	760	2
“ sulphate	$ZnSO_4 + 7H_2O$	2.02	50.	3	—	—	—

References: (1) Mond, Langer, Quincke; (2) Ordway; (3) Tilden; (4) Erdmann; (5) R. Weber; (6) Olszewski; (7) Birhaus; (8) Ramsay; (9) Deville; (10) Wroblewski; (11) Day, Sosman, White; (12) Ramme; (13) Meyer; (14) Lemoine; (15) Carnelly; (16) Mitscherlich; (17) LeChatelier; (18) Carnelly, O'Shea; (19) Thorpe; (20) Amat; (21) Mendelejeff; (22) Marignac; (23) Besson; (24) Clarke, Const. of Nature; (25) Isambert; (26) Mylius; (27) Hevesy; (28) Retgers; (29) Grünauer; (30) Richards and others.

* Under pressure 138 mm mercury. † Decomposes.

TABLE 240

DENSITIES AND MELTING AND BOILING POINTS OF ORGANIC COMPOUNDS

Substance	Chemical formula	Temp. °C	Density	Melting point	Boiling point	Authority or pressure for boiling point if not 760 mm
(a) Paraffin Series: C_nH_{2n+2}. Normal compounds only						
Methane	CH_4	−164	0.415	−184	−161.4	
Ethane	C_2H_6	− 88	.546	−172.0	− 88.3	
Propane	C_3H_8	− 44	.595	−189.9	− 44.5	
Butane	C_4H_{10}	0	.6011	−135.0	+ 0.6	
Pentane	C_5H_{12}	20	.631	−131.5	+ 36.2	
Hexane	C_6H_{14}	20	.660	− 94.3	69.0	
Heptane	C_7H_{16}	20	.684	− 90.0	98.4	
Octane	C_8H_{18}	17	.707	− 56.5	124.6	
Nonane	C_9H_{20}	20	.718	− 51	150.6	
Decane	$C_{10}H_{22}$	20	.747	− 32.0	174	
Undecane	$C_{11}H_{24}$	20	.741	− 26.5	197	
Dodecane	$C_{12}H_{26}$	20	.768	− 12	216	
Tridecane	$C_{13}H_{28}$	20	.757	− 6.2	234	
Tetradecane	$C_{14}H_{30}$	20	.765	+ 5.5	252.5	
Pentadecane	$C_{15}H_{32}$	20	.772	+ 10	270.5	
Hexadecane	$C_{16}H_{34}$	20	.775	20	287.5	
Heptadecane	$C_{17}H_{36}$	20	.778	22.5	303	
Octadecane	$C_{18}H_{38}$	20	.777	28	317	
Nonadecane	$C_{19}H_{40}$	32	.777	32	330	
Eicosane	$C_{20}H_{42}$	37	.778	38	205	15 mm
Heneicosane	$C_{21}H_{44}$	45	.775	40.4	215	15 mm
Docosane	$C_{22}H_{46}$	44	.778	44.4	224.5	15 mm
Tricosane	$C_{23}H_{48}$	48	.779	47.7	320.7	
Tetracosane	$C_{24}H_{50}$	61	.779	54	324	
Pentacosane	$C_{25}H_{52}$	20	.779	54	284	40 mm
Hexacosane	$C_{26}H_{54}$	20	.779	60	296	40 mm
Heptacosane	$C_{27}H_{56}$	60	.779	59.5	270	15 mm
Octacosane	$C_{28}H_{58}$	20	.779	65	318	40 mm
Nonacosane	$C_{29}H_{60}$	20	.780	63.6	348	40 mm
Triacontane	$C_{30}H_{62}$	20	.780	70	235	1.0 mm
Hentriacontane	$C_{31}H_{64}$	68	.781	68.1	302	15 mm
Dotriacontane	$C_{32}H_{66}$	79	.775	75	310	15 mm
Tetratriacontane	$C_{34}H_{70}$	20	.781	76.5	255	1.0 mm
Pentatriacontane	$C_{35}H_{72}$	75	.782	74.7	331	15 mm
Hexatriacontane	$C_{36}H_{74}$	76	.782	76.5	265	1.0 mm
(b) Olefines or the Ethylene Series: C_nH_{2n}. Normal compounds only						
Ethylene	C_2H_4	−102	.566	−169.4	−103.8	
Propylene	C_3H_6	− 47	.609	−185.2	− 47.0	
Butylene	C_4H_8	− 13.5	.635			Sieben
Amylene	C_5H_{10}	20	.651	−139	+ 36.4	
Hexylene	C_6H_{12}	0	.76		69	Wreden or Znatowicz
Heptylene	C_7H_{14}	20	.703		96–99	Morgan or Schorlemmer
Octylene	C_8H_{16}	17	.722		123	Möslinger
Nonylene	C_9H_{18}	15	.754		149.9	
Decylene	$C_{10}H_{20}$	0	.763		172	
Undecylene	$C_{11}H_{22}$	20	.763		188	
Dodecylene	$C_{12}H_{24}$	15	.762	− 31.5	96	15 mm
Tridecylene	$C_{13}H_{26}$	0	.845		232.7	
Tetradecylene	$C_{14}H_{28}$	20	.775	− 12	246	
Pentadecylene	$C_{15}H_{30}$		.814		247	Bernthsen
Hexadecylene	$C_{16}H_{32}$	20	.789	+ 4	274	
Octadecylene	$C_{18}H_{36}$	20	.791	+ 18	179	15 mm
Eicosylene	$C_{20}H_{40}$	0	.871		395	Beilstein
Cerotene	$C_{27}H_{54}$			58		Bernthsen
Melene	$C_{30}H_{60}$	20	.890	63	380	

DENSITIES AND MELTING AND BOILING POINTS OF ORGANIC COMPOUNDS

Substance	Chemical formula	Temp. °C	Density	Melting point	Boiling point	Authority or pressure for boiling point if not 760 mm
(*c*) Acetylene Series: C_nH_{2n-2}. Normal compounds only						
Acetylene	C_2H_2	−80	.613	− 81.8	− 83.6	Villard
Allylene	C_3H_4	−13	.660	−104.7	− 27.5	
Ethylacetylene	C_4H_6	0	.668	−130	+ 18.5	
Propylacetylene	C_5H_8	0	.722	− 95	+ 40	
Butylacetylene	C_6H_{10}			−150	71.5	
Amylacetylene	C_7H_{12}	13	.738	− 70	110.5	
Hexylacetylene	C_8H_{14}	0	.770		125	
Undecylidene					213	Bruylant
Dodecylidene		− 9	.810	− 9	105	Krafft, 15 mm
Tetradecylidene		+ 6.5	.806	+ 6.5	134	" " "
Hexadecylidene		20	.804	20	160	" " "
Octadecylidene		30	.802	30	184	" " "
(*d*) Monatomic alcohols: $C_nH_{2n+1}OH$. Normal compounds only						
Methyl alcohol	CH_3OH	20	.792	− 97.8	64.5	
Ethyl alcohol	C_2H_5OH	20	.789	−117.3	78.5	
Propyl alcohol	C_3H_7OH	20	.804	−127	97.8	
Butyl alcohol	C_4H_9OH	20	.810	− 89.8	117.7	
Amyl alcohol	$C_5H_{11}OH$	20	.817	− 78.5	137.9	
Hexyl alcohol	$C_6H_{13}OH$	20	.820	− 51.6	155.8	
Heptyl alcohol	$C_7H_{15}OH$	22	.817	− 34.6	175.8	
Octyl alcohol	$C_8H_{17}OH$	20	.827	− 16.3	194	
Nonyl alcohol	$C_9H_{19}OH$	20	.828	− 5	215	
Decyl alcohol	$C_{10}H_{21}OH$	20	.829	+ 7	231	
Undecyl alcohol	$C_{11}H_{23}OH$	20	.833	+ 19	146	30 mm
Dodecyl alcohol	$C_{12}H_{25}OH$	20	.831	24	259	
Tridecyl alcohol	$C_{13}H_{27}OH$	31	.822	30.5	156	15 mm
Tetradecyl alcohol	$C_{14}H_{29}OH$	38	.824	38	167	15 mm
Pentadecyl alcohol	$C_{15}H_{31}OH$			46		
Cetyl alcohol	$C_{16}H_{33}OH$	79	.798	49.3	344	
Octadecyl alcohol	$C_{18}H_{37}OH$	59	.812	58.5	210.5	15 mm
(*e*) Alcoholic ethers: $C_nH_{2n+2}O$						
Dimethyl ether	C_2H_6O	20	.6606	−138	− 24.9	
Diethyl ether	$C_4H_{10}O$	20	.714	−116.3	+ 34.5	β—123.3 b. pt.
Dipropyl ether	$C_6H_{14}O$	20	.747	−122	89	
Di-n-butyl ether	$C_8H_{18}O$	20	.769		149	
Di-sec-butyl ether	"	21	.756		121	
Di-iso-butyl ether	"	20	.762		122.5	
Diamyl ether	$C_{10}H_{22}O$	20	.774		190	
Di-iso-amyl ether	"	12	.783		172.2	
Dihexyl ether	$C_{12}H_{26}O$				208.8	
Diheptyl ether	$C_{14}H_{30}O$	0	.815		260	
Dioctyl ether	$C_{16}H_{34}O$	0	.820		291.8	
(*f*) Ethyl ethers: $C_nH_{2n+2}O$						
Ethyl-methyl	C_3H_8O	20	.697		+ 7.9	
" -propyl	$C_5H_{12}O$	20	.732	< −79	61.4	
" -isopropyl	"	0	.745		54	
" -n. butyl	$C_6H_{14}O$	20	.752		91.4	
" -iso-butyl	"	20	.751		80	Wurtz
" -iso-amyl	$C_7H_{16}O$	18	.764		112	
" -n. hexyl	$C_8H_{18}O$				137	
" -n. heptyl	$C_9H_{20}O$	16	.790		166.6	
" -n. octyl	$C_{10}H_{22}O$	17	.794		183	Möslinger

Where no reference is given the data were compiled from the International Critical Tables.

DENSITIES AND MELTING AND BOILING POINTS OF ORGANIC COMPOUNDS

(g) MISCELLANEOUS

Substance	Chemical formula.	Density and temperature.		Melting point C	Boiling point C	Authority.
Acetic acid	CH_3COOH	1.115	0°	16.7	118.5	Young, '09
Acetone	CH_3COCH_3	0.812	0	−94.6	56.1	
Aldehyde	C_2H_4O	0.806	0	−120.	+20.8	
Aniline	$C_6H_5NH_2$	1.038	0	−8.	183.9	
Beeswax		0.96 ±		62.		
Benzoic acid	$C_7H_6O_2$	1.293	4	121.	249.	
Benzene	C_6H_6	0.879	20	5.48	80.2	Richards
Benzophenone	$(C_6H_5)_2CO$	1.090	50	48.	305.9	Holborn-Henning
Butter		0.86–7		30 ±		
Camphor	$C_{10}H_{16}O$	0.99	10	176.	209.	
Carbolic acid	C_6H_5OH	1.060	21	43.	182.	
Carbon bisulphide	CS_2	1.292	0	−110.	46.2	
" tetrachloride	CCl_4	1.582	21	−30.	76.7	Young
Chlorbenzene	C_6H_5Cl	1.111	15	−40.	132.	
Chloroform	$CHCl_3$	1.4989	15	−63.3	61.2	
Cyanogen	C_2N_2	—		−35.	−21.	
Ethyl bromide	C_2H_5Br	1.45	15	−117.	38.4	
" chloride	C_2H_5Cl	0.918	8	−141.6	14.	
" ether	$C_4H_{10}O$	0.736	0	−118.	34.6	
" iodide	C_2H_5I	1.944	14	—	72.	
Formic acid	$HCOOH$	1.242	0	8.6	100.8	
Gasolene		0.68 ±		—	70–90	
Glucose	$CHO(HCOH)_4CH_2OH$	1.56		146.	—	
Glycerine	$C_3H_5O_3$	1.269	0	20.	290.	
Iodoform	CHI_3	4.01	25	119.	—	
Lard				29 ±	—	
Methyl chloride	CH_3Cl	0.992	−24	−103.6	−24.1	
Methyl iodide	CH_3I	2.285	15	−64.	42.3	
Naphthalene	$C_6H_4 \cdot C_4H_4$	1.152	15	80.	218.	Holborn-Henning
Nitrobenzene	$C_6H_5O_2N$	1.212	7.5	5.	211.	
Nitroglycerine	$C_3H_5N_3O_9$	1.60		—	—	
Olive oil		0.92		20 ±	300 ±	
Oxalic acid	$C_2H_2O_4 \cdot 2H_2O$	1.68		190.	—	
Paraffin wax, soft		—		38–52	350–390	
" " hard		—		52–56	390–430	
Pyrogallol	$C_6H_3(OH)_3$	1.46	40	133.	293.	
Spermaceti		0.95	15	45 ±	—	
Starch	$C_6H_{10}O_5$	1.56		none	—	
Sugar, cane	$C_{12}H_{22}O_{11}$	1.588	20	160.	—	
Stearine	$(C_{18}H_{35}O_2)_3C_3H_5$	0.925	65	71.	—	
Tallow, beef		0.94	15	27–38	—	
" mutton		0.94	15	32–41	—	
Tartaric acid	$C_4H_6O_6$	1.754		170.	—	
Toluene	$C_6H_5CH_3$	0.882	00	−92.	110.31	Richards
Xylene (o)	$C_6H_4(CH_3)_2$	0.863	20	−28.	142.	
" (m)	$C_6H_4(CH_3)_2$	0.864	20	54.	140.	
" (p)	$C_6H_4(CH_3)_2$	0.861	20	15.	138.	

MELTING POINTS

TABLE 241.—Melting Point of Mixtures of Metals

Metals.	Melting-points, °C											Reference.
	Percentage of metal in second column.											
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100 %	
Pb. Sn.	326	295	276	262	240	220	190	185	200	216	232	1
Bi.	322	290	–	–	179	145	126	168	205	–	268	7
Te.	322	710	790	880	917	760	600	480	410	425	446	8
Ag.	328	460	545	590	620	650	705	775	840	905	959	9
Na.	-	360	420	400	370	330	290	250	200	130	96	13
Cu.	326	870	920	925	945	950	955	985	1005	1020	1084	2
Sb.	326	250	275	330	395	440	490	525	560	600	632	16
Al. Sb.	650	750	840	925	945	950	970	1000	1040	1010	632	17
Cu.	650	630	600	560	540	580	610	755	930	1055	1084	18
Au.	655	675	740	800	855	915	970	1025	1055	675	1062	10
Ag.	650	625	615	600	590	580	575	570	650	750	954	17
Zn.	654	640	620	600	580	560	530	510	475	425	419	11
Fe.	653	860	1015	1110	1145	1145	1220	1315	1425	1500	1515	3
Sn.	650	645	635	625	620	605	590	570	560	540	232	17
Sb. Bi.	632	610	590	575	555	540	520	470	405	330	268	16
Ag.	630	595	570	545	520	500	505	545	680	850	959	9
Sn.	622	600	570	525	480	430	395	350	310	255	232	19
Zn.	632	555	510	540	570	565	540	525	510	470	419	17
Ni. Sn.	1455	1380	1290	1200	1235	1290	1305	1230	1060	800	232	17
Na. Bi.	96	425	520	590	645	690	720	730	715	570	268	13
Cd.	96	125	185	245	285	325	330	340	360	390	322	13
Cd. Ag.	322	420	520	610	700	760	805	850	895	940	954	17
Tl.	321	300	285	270	262	258	245	230	210	235	302	14
Zn.	322	280	270	295	313	327	340	355	370	390	419	11
Au. Cu.	1063	910	890	895	905	925	975	1000	1025	1060	1084	4
Ag.	1064	1062	1061	1058	1054	1049	1039	1025	1006	982	963	5
Pt.	1075	1125	1190	1250	1320	1380	1455	1530	1610	1685	1775	20
K. Na.	62	17.5	—10	—3.5	5	11	26	41	58	77	97.5	15
Hg.	–	-	-	–	–	90	110	135	162	265	–	13
Tl.	62.5	133	165	188	205	215	220	240	280	305	301	14
Cu. Ni.	1080	1180	1240	1290	1320	1335	1380	1410	1430	1440	1455	17
Ag.	1082	1035	990	945	910	870	830	788	814	875	960	9
Sn.	1084	1005	890	755	725	680	630	580	530	440	232	12
Zn.	1084	1040	995	930	900	880	820	780	700	580	419	6
Ag. Zn.	959	850	755	705	690	660	630	610	570	505	419	11
Sn.	959	870	750	630	550	495	450	420	375	300	232	9
Na. Hg.	96.5	90	80	70	60	45	22	55	95	215	–	13

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TABLE 242.—Melting Point of Alloys of Lead, Tin, and Bismuth

	Per cent.									
Lead	32.0	25.8	25.0	43.0	33.3	10.7	50.0	35.8	20.0	70.9
Tin	15.5	19.8	15.0	14.0	33.3	23.1	33.0	52.1	60.0	9.1
Bismuth	52.5	54.4	60.0	43.0	33.3	66.2	17.0	12.1	20.0	20.0
Solidification at	96°	101°	125°	128°	145°	148°	161°	181°	182°	234°

Charpy, Soc. d'Encours, Paris, 1901.

TABLE 243.—Melting Point of Low-melting-point Alloys

	Per cent.						
Cadmium	10.8	10.2	14.8	13.1	6.2	7.1	6.7
Tin	14.2	14.3	7.0	13.8	9.4	–	-
Lead	24.9	25.1	26.0	24.3	34.4	39.7	43.4
Bismuth	50.1	50.4	52.2	48.8	50.0	53.2	49.9
Solidification at	65.5°	67.5°	68.5°	68.5°	76.5°	89.5°	95°

Drewitz, Diss. Rostock, 1902.

All compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

Table 244

MELTING POINT OF SOME REFRACTORY SUBSTANCES

(Compiled by F. C. Kracek, Geophysical Laboratory, Carnegie Institution, 1930.)

Symbols: m, melting point; r, reaction temperature, resulting in the break up of a compound into another and liquid; d, compound decomposes before melting with evolution of gas; vac, melting in vacuo.

Compound	t°C	Type	Ref.
Al_2O_3	2050 ± 10	m	22
BN	1240	d	37
BaO	1923 ± 10	m	36
BeO	2400 ± 50	m	34
CaO	2572 ± 10	m	36
Ce_2O_3	1692	m	14
FeO?	1419	vac	15
Fe_2O_3	1560	d	15
Fe_3O_4	1540	d	15
La_2O_3	>2000	m	39
Li_2O	>1650	m	19
MgO	2800 ± 20	m	22, 34
MnO	>1650	vac	39
PbO	888 ± 10	m	8
SiO_2	1713 ± 10	m	12, 16
SrO	2430 ± 10	m	36
ThO_2	3050 ± 25	m	35
TiO_2	<1640	d	39
Yt_2O_3	2410	m	34
ZnO	1975 ± 25	m	7
ZrO_2	2690	m	40
BINARY SILICATES			
$2BaO.SiO_2$	>1755	m	11
$BaO.SiO_2$	1604 ± 5	m	11
$2BaO.3SiO_2$	1450 ± 2	m	11
$BaO.2SiO_2$	1420 ± 4	m	11
$BeO.SiO_2$	>1755	m	21
$3CaO.SiO_2$	1900 ± 20	r	9
$2CaO.SiO_2$	2130 ± 20	m	9
$3CaO.2SiO_2$	1475 ± 5	r	9
$CaO.SiO_2$	1540 ± 2	m	9
$2CdO.SiO_2$	1242 ± 2	m	20
$CdO.SiO_2$	1242 ± 2	m	20
$K_2O.SiO_2$	976	m	26
$K_2O.2SiO_2$	1036 ± 1	m	24
$K_2O.4SiO_2$	765 ± 0.5	m	24
$2Li_2O.SiO_2$	1256 ± 5	r	19
$Li_2O.SiO_2$	1201 ± 2	m	10
$Li_2O.2SiO_2$	1032 ± 5	r	19
$2MnO.SiO_2$	1323	r	20
$MnO.SiO_2$	1273 ± 5	m	20
$2MgO.SiO_2$	1890 ± 20	m	3
$MgO.SiO_2$	1557 ± 2	r	3
$2Na_2O.SiO_2$	1120 ± 5	r	23
$Na_2O.SiO_2$	1088 ± 2	m	17, 23
$Na_2O.2SiO_2$	875 ± 1	m	28, 23
$2PbO.SiO_2$	746 ± 10	m	8
$PbO.SiO_2$	766 ± 10	m	8
$2SrO.SiO_2$	>1755	m	21
$SrO.SiO_2$	1580 ± 4	m	11
$2ZnO.SiO_2$	1512 ± 5	m	7
$ZnO.SiO_2$?	1437	r?	21
$ZrO_2.SiO_2$	2550 ± 50	m	40

Compound	t°C	Type	Ref.
BINARY ALUMINATES			
$3CaO.Al_2O_3$	1535 ± 5	r	9
$5CaO.3Al_2O_3$	1455 ± 5	m	9
$CaO.Al_2O_3$	1600 ± 5	m	9
$3CaO.5Al_2O_3$	1720 ± 10	m	9
$Li_2O.Al_2O_3$	>1625	m	18
$MgO.Al_2O_3$	2135 ± 20	m	32
$Na_2O.Al_2O_3$	1650	m	25
ALUMINO-SILICATES			
$BaO.Al_2O_3.2SiO_2$	>1700	..	11
$2CaO.Al_2O_3.SiO_2$	1590 ± 2	m	13, 32
$CaO.Al_2O_3.2SiO_2$	1550 ± 2	m	9
$K_2O.Al_2O_3.2SiO_2$	>1755	m	4
$K_2O.Al_2O_3.4SiO_2$	1686 ± 5	m	6
$K_2O.Al_2O_3.6SiO_2$	1170	r	27
$Li_2O.Al_2O_3.2SiO_2$	1388 ± 5	m	18
$Li_2O.Al_2O_3.4SiO_2$	1400 ± 3	m	18
$Na_2O.Al_2O_3.2SiO_2$	1526 ± 2	m	4
$Na_2O.Al_2O_3.6SiO_2$	1100 ± 10	m	4
$SrO.Al_2O_3.2SiO_2$	>1700	m	11
$2SiO_2.3Al_2O_3$	1810 ± 10	r	5
TERNARY CALCIUM SILICATES			
$BaO.2CaO.3SiO_2$	1320 ± 4	r	11
$K_2O.CaO.SiO_2$	......	m	30
$2K_2O.CaO.3SiO_2$	1010 ± 5	r	30
$K_2O.3CaO.6SiO_2$	1015 ± 5	r	30
$4K_2O.CaO.10SiO_2$	946 ± 1	m	30
$2K_2O.CaO.6SiO_2$	959 ± 1	m	30
$K_2O.2CaO.6SiO_2$	1115 ± 5	r	30
$K_2O.2CaO.9SiO_2$	1025 ± 5	r	30
$MgO.CaO.SiO_2$	1498 ± 5	r	12
$MgO.2CaO.2SiO_2$	1458 ± 2	m	12
$2MgO.5CaO.6SiO_2$	1365 ± 5	r	12
$MgO.CaO.2SiO_2$	1391 ± 2	m	10, 2
$2Na_2O.CaO.3SiO_2$	1141 ± 5	r	29
$Na_2O.2CaO.3SiO_2$	1284 ± 5	m	29
$Na_2O.3CaO.6SiO_2$	1047	r	29
MISCELLANEOUS COMPOUNDS			
$2CaO.Fe_2O_3$	1436 ± 5	r	38
$CaO.Fe_2O_3$	1216 ± 5	r	38
$2CaO.B_2O_3$	1304 ± 5	m	33
$CaO.ZrO_2$	2350 ± 25	m	35
$K_2O.2TiO_2$	980	m	31
$Na_2O.Fe_2O_3.4SiO_2$	990 ± 10	r	6

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Table 245

ENANTISTROPIC INVERSIONS IN CRYSTALS

(Arranged by F. C. Kracek, Geophysical Laboratory, Carnegie Institution, 1931.)

Values are given, for the more important crystals, of the inversion temperature in °C, the heat of inversion in cal./g and the inversion volume change in cm³/g. No monotropic inversions have been included.

h_i, inversion temperature on heating; m, metastable inversion temperature; e, estimated; g, gradual inversion (not to be confused with slow retarded inversions).

Substance	Phases	Inversion t°C	Pressure atm.	Inversion heat cal./g	Inversion volume change cm³/g	Reference
$AgClO_4$	....	158	....	....	....	1
$AgBrO_3$	....	98.5	....	....	....	2
AgI	I-II	146	1	5.72	.0086	3
		99.4	2720	4.95	.0101	3
	I-III	99.4	2720	4.22	.0140	3
	II-III	99.4	2720	.76	.0241	3
Ag_2S	....	175	....	3.85	....	4
Ag_2Se	....	133	....	5.65	....	5
Ag_2SO_4	....	412	....	....	....	6
$AgNO_3$	....	159.5	....	3.37	.0025	7
$AlBr_3$	....	70	....	....	....	8
As_2O_3	....	275	....	6	....	9
As_2S_2	red-black	267	....	....	....	10
As_2S_3	red-yellow	170	....	....	....	10
Bi_2O_3	....	704*	....	....	....	11
$BaCl_2$	....	924	....	....	....	12
$BaClO_4$	....	284	....	....	....	1
$BaSO_4$	....	1149	....	....	....	13
$BaCO_3$	....	811 & 982	....	....	....	14
Br_3O_8	....	−35	....	....	....	15
C	diamond-	25	>8000	16	....	16
	β graphite					17
CO	g	−212.8	....	5.4	....	18
CH_4	g	−252.7	....	1.15	....	18
CH_3OH	g	−112	....	4.8	....	19
CCl_4	I-II	−48.5	1	7.1	.026(e)	20
		115	8460	9.8	.0173	3
	II-III	115	8460	.9	.0054	3
	I-III	115	8460	10.7	.0227	3
CBr_4	I-II	46.2	1	5.04	.0205	3
		112.6	2110	4.58	.0150	3
	I-III	112.6	2110	.25	.0029	3
	II-III	112.6	2110	4.66	.0121	3
CH_2I_2	L-I-II	8.6	180	....	....	3
	L-II-III	42.8	1930	....	....	3
	I-II-IV	9.4	325	....	....	3
	II-III-IV	38	1825	....	....	3
CH_4N_2O	I-II	102.3	6535	2.34	.0480	3
(Urea)	I-III	102.3	6535	10.14	.0486	3
	II-III	102.3	6535	7.80	.0006	3
CH_3COOH	L-I	16.68	1	45	.1560	3
		55.7	2033	46.4	.0862	3
	L-II	55.7	2033	48.2	.0992	3
	I-II	55.7	2033	1.85	.0130	3
CH_3CONH_2	L-I	127	5220	60.9	.0319	7
(Acetamide)	L-II	127	5220	58.5	.0649	7
	I-II	127	5220	2.41	.0330	7
$(CH_3)_2CO$†	I-II	−140 to −150	....	<0.5	....	19

* Third modification at room temperature. † Acetone.

ENANTISTROPIC INVERSIONS IN CRYSTALS

Substance	Phases	Inversion t°C	Pressure atm.	Inversion heat cal./g	Inversion volume change cm³/g	Reference
C_2Cl_6	I-II	71.1	1	6.93	0.0280	7
(Perchlor ethane)	II-III	42.7	1	2.63	.0097	7
$C_3H_7NO_2$ (Urethane)	L-I	47.9	1	40.7	.0599	7
		66.2	2270	37.9	.0253	7
	L-II	66.2	2270	35.9	.0355	7
		76.8	4090	34.4	.0184	7
	L-III	76.8	4090	40.6	.0640	7
	I-II	66.2	2270	2.07	.0102	7
		25.5	3290	1.64	.0092	7
	II-III	76.8	4090	6.12	.0456	7
		25.5	3290	5.50	.0482	7
	I-III	25.5	3290	3.87	.0574	7
C_6H_6 (Benzene)	I-II	100	11680	8.68	.0105	21
		218	11680	7.73(e)	.0132(e)	21
	L-I	5.4	1	30.2	.1317	21
		218	11680	33.25(e)	.0369(e)	21
	L-II	218	11680	25.5(e)	.0501(e)	21
C_6H_5OH (Phenol)	L-I	40.9	1	29.8	.0567	22
		64	2015	24.8	.0270	7
	L-II	64	2015	30	.0825	7
	I-II	64	2015	5.2	.0555	7
$CH_3C_6H_4OH$ (o.Cresol)	L-I	30.8	1	33.8	.0838	21
		103.2	5900	34.2	.0317	21
	L-II	103.2	5900	35	.0555	21
	I-II	103.2	5900	.8	.0238	21
Camphor*	I-II	87.1	1	.25	.00187	7
$C_6H_{11}OH$†	I-II	−9	1	9.38	....	19
$C_6H_5NH_2HNO_3$†	....	97.6	....	....	....	23
$CaSO_4$	....	1193	....	....	....	13
$CaCO_3$§	I-II	970	high CO_2	....	....	14
$CaO.SiO_2$	....	1190 ± 10	....	Ca. 10	....	25
$2CaO.SiO_2$	....	1420, 675	....	....	10%, 675	26
Co	Curie point	~1100	....	1.3	....	27
	I-II	1015	....	....	....	28
	II-III	400	....	....	....	28
CoO	....	350 ± 10	....	....	....	29
CoOH	....	223	....	11.8	....	30
CsCl	....	460	....	8	....	31
$CsClO_4$	....	219	....	....	....	1
Cs_2SO_4	....	660	....	....	....	32
$CsNO_3$	....	153.5	1	4.3	.00405	7
$Cs_2Ca_2(SO_4)_3$	....	722	....	....	....	32
Cu_2Br_2	I-II-III	390, 470	....	....	....	33
Cu_2I_2	I-II-III	402, 440	1	....	....	33
	II-III	200	9600	1.091	.00485	3
	II-III	100	11560	.948	.00535	3
Cu_2S	....	91	....	5.6	....	34
Cu_2Se	....	110	....	5.4	....	34
Cu_2Te	....	351, 387	....	....	....	35
Fe	Curie point	730	....	6.7 ±	....	27
	β-γ	920	....	6.7 ±	....	..
	γ-δ	1400	....	2	....	..
Fe_3O_4	Curie point	570±	....	....	....	36
Fe_2O_3	II-III	−163 to −148	....	2.25	....	37
	I-II	500±	....	....	....	..
FeS	....	140	....	....	....	38
FeS_2	pyrite, marcasite	....	....	....	....	39

* Five other modifications; not accurately located. † Cyclo-hexanol.
§ Very beautiful for demonstration purposes.

ENANTISTROPIC INVERSIONS IN CRYSTALS

Substance	Phases	Inversion t°C	Pressure atm.	Inversion heat cal./g	Inversion volume change cm^3/g	Reference
Fe_2P	....	80	....	....	....	40
Fe_3P	....	440	....	....	....	40
$FeTiO_3$	....	215	....	....	....	41
HgI_2	red-yellow	127.5	....	1.3	0.00342	3
Hg_2I_2	green-yellow	....	....	.5±	....	42
HgS	{cinnabar / metacinnabar}	386±	....	....	....	39
ICl	ruby-brown	....	....	....	....	43
KOH	....	248	....	27.1	....	30
$KClO_3$	I-II	255	....	....	....	3
	II-III	$P = 5500 + 10.9\,t$				3
	$\Delta v_i = 0.02510 - 2.2\,t \times 10^{-6}$	$\Delta h_i = 0.165$ at 0°, 0.281 at 200°				3
$KClO_4$	....	295	....	....	....	1
K_2S	I-II	146.4	1	.765	.00095	3
		$t = 146.4 + 0.0124\,p$				
KNO_3	I-II	127.7	1	10.5	.00484	7
		128	81	10.3	.0049	44
	I-III	128	81	5.6	.0138	44
	II-III	128	81	4.7	.0089	44
		21.3	2840	1.3	.0156	7
	III-IV	21.3	2840	5.1	.0284	7
	II-IV	21.3	2840	3.8	.0440	7
K_2SO_4		588	....	13	....	45
$KHSO_4$	I-II	180.5	1	.71	.00066	3
		198.6	1773	2.29	.00197	3
	II-III	164.2	1	3.61	.00566	3
		118.2	2810	3.30	.00570	3
	II-IV	198.6	1773	.166	.00113	3
		118.2	2810	.134	.00110	3
	I-IV	198.6	1773	2.03	.00310	3
	III-IV	118.2	2810	3.44	.00680	3
KPO_3	....	450	....	....	....	46
$K_4P_2O_7$	....	278	....	....	....	46
K_2CO_3	....	410	....	....	....	22
$KCNS$	....	143	1	3.10	.00306	3
$K_2Pb(SO_4)_2$	....	544	....	....	....	32
K_2CdI_4	....	215	....	....	....	47
K_2CrO_4	....	666	....	12.6	..	48
$K_2Cr_2O_7$	....	243	....	1.40	....	45
K_2MoO_4	....	327, 454, 477	....	....	....	49
K_2WO_4	....	388	....	8.2	....	45
	....	575	....	1.6	....	45
$K_2Ca_2(SO_4)_3$	....	937	....	....	....	32
$K_2Sr(SO_4)_3$	....	775	....	....	....	32
$KLiSO_4$	....	435	....	....	....	32
KNO_2	I-II	−0.3	5000	11.7	.0315	3
		122.3	10000	7.15	.0378	3
$K_2O(SiO_2)_2$	....	290	....	....	....	45
$2K_2O(Al_2O_3)(SiO_2)_4$*	....	714	....	....	....	50
$LiClO_3$	....	41.5, 99	....	....	....	51
Li_2SO_4	....	580	....	55 ± 1	....	45
$(MgO)_6(B_2O_3)_8MgCl$	....	266	....	1.8	....	52
$MgO.SiO_2$†	....	....	....	....	....	53
Mn	....	742, 1191	....	....	....	54
$MnSO_4$	....	860	....	....	....	55
MnO_2	....	−185 to −175	....	.88	....	37
MnO	....	−153 to −163	....	2.08	....	37
N_2	....	−237.6	....	1.9(g)	....	56
NH_4Cl	....	− 30.5(g)	....	....	....	57
	I-II	184.3	....	16.3	.0985	3

* Leucite. † Probably pentamorphic, inv. at 1150 and 1300°.

TABLE 245 *(continued)*

ENANTISTROPIC INVERSIONS IN CRYSTALS

Substance	Phases	Inversion t°C	Pressure atm.	Inversion heat cal./g	Inversion volume change cm³/g	Reference
NH_4Br	....	−38 (g)	....	....	....	57
	I-II	137.8	1	7.78	0.0647	3
NH_4I	....	−42.5(g)	....	....	....	57
	I-II	−17.6	1	4.80	.0561	3
NH_4ClO_4	....	240	....	....	....	58
NH_4HSO_4	I-II-III	126.2	1800	....	....	3
	II-III-IV	176.9	5480	....	....	3
$(NH_4)_3H(SO_4)_2$	....	134	....	....	....	59
NH_4CNS	I-II	120	....	....	....	60
	II-III	87.7	1	10.36	.0409	3
NH_4NO_3	L-I	169.5	1	16	.051	7
	I-II	125.5	1	12.9	.01351	7
		186.7	8730	12.6	.00475	7
	I-VI	186.7	8730	12.3	.00855	7
	II-VI	169.2	8870	.27	.00309	7
		186.7	8730	.33	.00380	7
	II-III	84	1	4	.00758	7
		63.3	830	2.48	.00925	7
	III-IV	32	1	4.67	.02026	7
		63.3	830	4.03	.02135	7
	II-IV	63.3	830	6.51	.01210	7
		169.2	8870	11.84	.01267	7
	IV-VI	169.2	8870	12.1	.00958	7
	IV-V	−18	1	1.6	.017	7
$NaOH$	....	300	....	24.7	....	30
$NaClO_4$	....	308	....	....	....	58
$NaClO_3$	....	248	....	....	....	61
Na_2SO_4	IV-III	185	....	8.6	,.0034	62
	III-I	241	....	15.5	.0070	62
$NaF.Na_2SO_4$	....	105	....	....	....	..
Na_2CO_3	....	430	....	....	....	22
$NaNO_3$	....	275(g)	....	(8 ± 2)	(.0081)	45
Na_3AlF_6	....	568	....	59	....	63
Na_2MoO_4	....	424, 585, 623	....	....	....	64
Na_2WO_4	I-II	588	....	33.6	....	45
	I-III	586m	....	4.4	....	45
	III-II	m	....	29.2	....	45
$NaAlSiO_4$	neph.—carn.	1250	....	....	....	65
	carnegicite	226, 650–690	....	ca 1	....	65
$NaC_2H_3O_2$*	....	198†	....	....	....	58
Ni	Curie pt.	355	....	....	....	27
Ni_3S_2	....	545	....	....	....	66
Ni_5As_2	....	970	....	....	....	67
Oxygen	I-II	−229.5	....	6.2	....	18
	II-III	−249.5	....	.75	....	18
Phosphorus	L-I	44.2	1	4.90	.0193	3
		196	6000	6.53	.0120	3
	I-II	0.1	6000	43.9	.00846	3
		68.4	12000	55.2	.00684	3
PbO	red-yellow	587	....	....	....	64
$PbSO_4$	....	870	....	13.4	....	68
$PbCrO_4$	....	707, 783	....	....	....	64
$PbWO_4$	....	877	....	....	....	64
RbOH	....	245	....	16.8	....	30
$RbClO_4$	....	279	....	....	....	1
Rb_2SO_4	....	653	....	....	....	32
$Rb_2Ca_2(SO_4)_3$	....	787, 915	....	....	....	32
$RbLiSO_4$	....	142	....	....	....	32

* Acetate. † Sluggish.

ENANTISTROPIC INVERSIONS IN CRYSTALS

Substance	Phases	Inversion t°C	Pressure atm.	Inversion heat cal./g	Inversion volume change cm³/g	Reference
$RbNO_3$	I-II	219	....	....	....	69
	II-III	164.4	1	7.12	0.00688	7
	....	218.6	5810	5.93	.00434	7
RbCl	....	50	5525	....	....	70
RbBr	....	50	4925	....	....	70
RbI	....	50	4050	....	....	70
Sulphur	I-II	95.5	1	2.7	....	71
	L-I-II	155	1410	....	....	22
Sb	expl.-common	....	....	19	....	72
Sb_2O_3	rhomb.-reg.	570	....	....	....	73
$SbCl_3$	I-II-III	65, 69.5	....	....	....	8
SiO_2*	I-II	573	....	2.6	....	45
SiO_2†	I-II	215	....	2.7	....	45
SiO_2§	I-II	150h	....	.63	....	45
	II-III	104h	....	.96	....	45
SiO_2	*—§	870	....	8.7(e)	....	74
	*—†	1250	....	25 (e)	....	75
	§—†	1470	....	7.5(e)	....	45
Sn	....	161	....	.2	small	77
	....	18	....	4.4	....	72
SnO_2	....	430, 540	....	....	....	..
$SrSO_4$	....	1152	....	....	....	13
$SrCO_3$	....	925	high CO_2	....	....	14
$TlClO_4$	....	226	....	....	....	1
TlI	....	173	....	....	....	79
$TlNO_3$	I-II	144.6	1	2.86	.00244	7
	II-III	75	1	.89	.00073	7
Tl picrate	....	44	....	....	.018	80
Tl	....	230	....	.3±	....	77
TiO_2	Rutile, anatase, brookite, stability relations unknown					
$TiBr_4$	....	−15	....	....	....	81
W_2C	....	2400	....	....	....	82
Zn	....	175, 300	....	....	....	83
ZnS‡	....	1020	....	....	....	39
ZrO_2	....	ca 1000	....	....	....	84

(1) Vorländer, 1923. (2) Reedy, 1921. (3) Bridgman, 1915. (4) Rinne, 1924. (5) Bellatti, 1889. (6) Nacken, 1907. (7) Bridgman, 1916. (8) Kendall, 1923. (9) Rushton, Daniels, 1926. (10) Borodorvski, 1906. (11) Guertler, 1903. (12) Vortisch, 1914. (13) Grahmann, 1913. (14) Boeke, 1913. (15) Lewis, Schumacher, 1929. (16) Roth, 1925. (17) G. N. Lewis, 1923. (18) Clusius, 1929. (19) Kelley, 1929. (20) Latimer, 1922. (21) Bridgman, 1914. (22) Tammann, 1903. (23) Wallerant, 1915. (24) Bäckstrom, 1921, 1925. (25) White, 1919. (26) Day, 1906. (27) Various. (28) Hendrichs, 1930. (29) Emmett-Schulz, 1930. (30) Hevesy, 1910. (31) Zemcuzny, Rambach, 1910. (32) Müller, 1910. (33) Tubandt, 1928. (34) Bellati, 1889. (35) Chicaschigé, 1907. (36) Baudisch-Welo, 1925. (37) Millar, 1928. (38) Rinne, Boeke, 1907. (39) Allen, 1912. (40) le Chatelier, 1909. (41) Königsberger, 1910. (42) Varet, 1896. (43) Stortenbeker, 1889. (44) Kracek, 1930. (45) Kracek, 1931. (46) Amadori, 1913. (47) Brand, 1912. (48) Hare, 1924. (49) Van Klooster, 1914. (50) Rinne, 1910. (51) Kraus, Burgess, 1927. (52) Kroeker, 1892. (53) Allen, White, 1909. (54) Perrson, Öhmann, 1929. (55) Friedrichs, 1910. (56) Eucken, 1924. Clusius, 1929. (57) Simon, 1927. (58) Vorländer, 1923. (59) Fischer, 1911. (60) Vresnevsky. (61) Retgers. (62) Kracek, Gibson, 1929. (63) Roth, 1929. (64) Jaeger, Germs, 1921. (65) Bowen, Greig, 1925. (66) Friedrichs, 1914. (67) Friedrichs, 1907. (68) Hare, 1924. (69) Schwarz, 1892. (70) Bridgman, 1928. (71) Mondain, Monval, 1926. (72) Cohen, 1915. (73) Fenwick, 1927. (74) Fenner, 1913. (75) White, 1909, 1919. (76) Wietzel, 1921. (77) Werner, 1913. (78) Brönsted, 1913. (79) Gernez, 1904. (80) Cohen, 1920. (81) Baltz, Jelp, 1927. (82) Becker, 1928. (83) Saldan, 1930. (84) Böhm, 1925.

* Quartz. † Cristobalite. ‡ Zincblende and wurtzite. § Tridymite.

Table 246

TRANSFORMATION AND MELTING TEMPERATURES OF LIME-ALUMINA-SILICA COMPOUNDS AND EUTECTIC MIXTURES

The majority of these determinations are by G. A. Rankin. (Part unpublished.)

Substance.	% CaO	Al_2O_3	SiO_2	Transformation.	Temp.
$CaSiO_3$	48.2	—	51.8	Melting	1540° ±2°
$CaSiO_3$	48.2	—	51.8	α to β and reverse	1200 ±2
Ca_2SiO_4	65.	—	35.	Melting	2130 ±10
"	65.	—	35.	γ to β and reverse	675 ±5
"	65.	—	35.	β to α and reverse	1420 ±2
$Ca_3Si_2O_7$	58.2	—	41.8	Dissociation into Ca_2SiO_4 and liquid	1475 ±5
Ca_3SiO_5	73.6	—	26.4	Dissociation into Ca_2SiO_4 and CaO	1900 ±5
$Ca_3Al_2O_6$	62.2	37.8	—	Dissociation into CaO and liquid	1535 ±5
$Ca_5Al_6O_{14}$	47.8	52.2	—	Melting	1455 ±5
$CaAl_2O_4$	35.4	64.6	—	Melting	1600 ±5
$Ca_3Al_{10}O_{18}$	24.8	75.2	—	Melting	1720 ±10
Al_2SiO_5	—	62.8	37.1	Melting	1816 ±10
$CaAl_2Si_2O_8$	20.1	36.6	43.3	Melting	1550 ±2
$Ca_2Al_2SiO_7$	40.8	37.2	22.0	Melting	1590 ±2
$Ca_3Al_2SiO_8$	50.9	30.9	18.2	Dissociation into Ca_2SiO_4+ $Ca_2Al_2SiO_7$ and liquid	1335 ±5

EUTECTICS.

Crystalline Phases.	% CaO	Al_2O_3	SiO_2	Melting Temp.
$CaSiO_3,SiO_2$	37.	—	63.	1436°
Ca,SiO_3 $3CaO,2SiO_2$	54.5	—	45.5	1455±
Ca_2SiO_4 CaO.	67.5	—	32.5	2065±
Al_2SiO_5,SiO_2	—	13.	87.	1610
Al_2SiO_5,Al_2O_3	—	64.	36.	1810
$CaAl_2Si_2O_8$ $CaSiO_3$	34.1	18.6	47.3	1299
$CaAl_2Si_2O_8$ SiO_2	10.5	19.5	70.	1359
$CaAl_2Si_2O_8$ $SiO_2,CaSiO_3$	23.2	14.8	62.	1165
$Ca_2Al_2SiO_7$ Ca_2SiO_4	49.6	23.7	26.7	1545
Al_2O_3 $CaAl_2Si_2O_8$	19.3	39.3	41.4	1547
$CaAl_2Si_2O_8$ Al_2SiO_5,SiO_2	9.8	19.8	70.4	1345
$Ca_2Al_2SiO_7$ $Ca_3Al_{10}O_{18}$	35.	50.8	14.2	1552
$Ca_2Al_2SiO_7$ $CaAl_2O_4$	37.8	52.9	9.3	1512
$Ca_2Al_2SiO_7$ $CaAl_2O_4$ $Ca_3Al_{10}O_{18}$	37.5	53.2	9.3	1505
$CaAl_2Si_2O_8$ $Ca_2Al_2SiO_7$	30.2	36.8	33.	1385
$Ca_2Al_2SiO_7$ $Ca_3Si_2O_7$ $CaSiO_3$	47.2	11.8	41.	1310
$Ca_2Al_2SiO_7$ $CaSiO_3$	45.7	13.2	41.1	1316

EUTECTICS.

Crystalline Phases.	% CaO	Al_2O_3	SiO_2	Melting Temp.
$CaAl_2Si_2O_8$ $Ca_2Al_2SiO_7$ Ca_2SiO_4	38.	20.	42.	1265°
$CaAl_2Si_2O_8$ $Ca_2Al_2SiO_7$ Al_2O_3	29.2	39.	31.8	1380
Ca_2SiO_4 $CaAl_2O_4$ $Ca_5Al_6O_{14}$	49.5	43.7	6.8	1335
QUINTUPLE POINTS.				
$Ca_2Al_2SiO_7$ $Ca_3Si_2O_7$ Ca_2SiO_4	48.2	11.9	39.9	1335
$Ca_2Al_2SiO_7$ Ca_2SiO_4 $CaAl_2O_4$	48.3	42.	9.7	1380
$CaAl_2Si_2O_8$ Al_2O_3 Al_2SiO_5	15.6	36.5	47.9	1512
$Ca_3Al_{10}O_{18}$ $Ca_2Al_2SiO_7$ Al_2O_3	31.2	44.5	24.3	1475
QUADRUPLE POINTS.				
$3CaO.2SiO_2$ $2CaO.SiO_2$	55.5	—	44.5	1475

The accuracy of the melting-points is 5 to 10 units. Geophysical Laboratory. See also Day and Sosman, Am. J. of Sc. xxxi, p. 341, 1911.

Table 247

LOWERING OF FREEZING POINTS BY SALTS IN SOLUTION

In the first column is given the number of gram-molecules (anhydrous) dissolved in 1000 grams of water; the second contains the molecular lowering of the freezing point; the freezing point is therefore the product of these two columns. After the chemical formula is given the molecular weight, then a reference number.

g. mol. / 1000 g. H_2O	Molecular Lowering.
$Pb(NO_3)_2$, 331.0: 1, 2.	
0.000362	5.5°
.001204	5.30
.002805	5.17
.005570	4.97
.01737	4.69
.5015	2.99
$Ba(NO_3)_2$, 261.5: 1.	
0.000383	5.6°
.001259	5.28
.002681	5.23
.005422	5.13
.008352	5.04
$Cd(NO_3)_2$, 236.5: 3.	
0.00298	5.4°
.00689	5.25
.01997	5.18
.04873	5.15
$AgNO_3$, 167.0: 4, 5.	
0.1506	3.32°
.5001	2.96
.8645	2.87
1.749	2.27
2.953	1.85
3.856	1.64
0.0560	3.82
.1401	3.58
.3490	3.28
KNO_3, 101.9: 6, 7.	
0.0100	3.5
.0200	3.5
.0500	3.41
.100	3.31
.200	3.19
.250	3.08
.500	2.94
.750	2.81
1.000	2.66
$NaNO_3$, 85.09: 2, 6, 7	
0.0100	3.6°
.0250	3.46
.0500	3.44
.2000	3.345
.500	3.24
.5015	3.30
1.000	3.15
1.0030	3.03
NH_4NO_3, 80.11: 6, 8	
0.0100	3.6°
.0250	3.50
0.0500	3.47°
.1000	3.42
.2000	3.32
.500	3.26
1.000	3.14
$LiNO_3$, 69.07: 9.	
0.0398	3.4°
.1671	3.35
.4728	3.35
1.0164	3.49
$Al_2(SO_4)_3$, 342.4: 10.	
0.0131	5.6°
.0261	4.9
.0543	4.5
.1086	4.03
.217	3.83
$CdSO_4$, 208.5: 1, 11.	
0.000704	3.35°
.002685	3.05
.01151	2.69
.03120	2.42
.1473	2.13
.4129	1.80
.7501	1.76
1.253	1.86
K_2SO_4, 174.4: 3, 5, 6, 10, 12.	
0.00200	5.4°
.00398	5.3
.00865	4.9
.0200	4.76
.0500	4.60
.1000	4.32
.200	4.07
.454	3.87
$CuSO_4$, 159.7: 1, 4, 11.	
0.000286	3.3°
.000843	3.15
.002279	3.03
.006670	2.79
.01463	2.59
.1051	2.28
.2074	1.95
.4043	1.84
.8898	1.76
$MgSO_4$, 120.4: 1, 4, 11.	
0.000675	3.29
.002381	3.10
.01263	2.72
.0580	2.65
.2104	2.23
0.4978	2.02°
.8112	2.01
1.5233	2.28
$BaCl_2$, 208.3: 3, 6, 13.	
0.00200	5.5°
.00498	5.2
.0100	5.0
.0200	4.95
.04805	4.80
.100	4.69
.200	4.66
.500	4.82
.586	5.03
.750	5.21
$CdCl_2$, 183.3: 3, 14.	
0.00299	5.0°
.00690	4.8
.0200	4.64
.0541	4.11
.0818	3.93
.214	3.39
.429	3.03
.858	2.71
1.072	2.75
$CuCl_2$, 134.5: 9	
0.0350	4.9°
.1337	4.81
.3380	4.92
.7149	5.32
$CoCl_2$, 129.9: 9.	
0.0276	5.0°
.1094	4.9
.2369	5.03
.4399	5.30
.538	5.5
$CaCl_2$, 111.0: 5, 13–16.	
0.0100	5.1°
.05028	4.85
.1006	4.79
.5077	5.33
.946	5.3
2.432	8.2
3.469	11.5
3.829	14.4
0.0478	5.2
.153	4.91
.331	5.15
.612	5.47
.998	6.34
$MgCl_2$, 95.26: 6, 14.	
0.0100	5.1°
.0500	4.98
.1500	4.96
.3000	5.186
.6099	5.69
KCl, 74.60: 9, 17–19.	
0.02910	3.54°
.05845	3.46
.112	3.43
.3139	3.41
.476	3.37
1.000	3.286
1.989	3.25
3.269	3.25
$NaCl$, 58.50: 3, 20, 12, 16.	
0.00399	3.7°
.01000	3.67
.0221	3.55
.04949	3.51
.1081	3.48
.2325	3.42
.4293	3.37
.700	3.43
NH_4Cl, 53.52: 6, 15.	
0.0100	3.6°
.0200	3.56
.0350	3.50
.1000	3.43
.2000	3.396
.4000	3.393
.7000	3.41
$LiCl$, 42.48: 9, 15	
0.00992	3.7°
.0455	3.5
.09952	3.53
.2474	3.50
.5012	3.61
.7939	3.71
$BaBr_2$, 297.3: 14	
0.100	5.1°
.150	4.9
.200	5.00
.500	5.18
$AlBr_3$, 267.0: 9.	
0.0078	1.4°
.0559	1.2
.1971	1.07
.4355	1.07

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Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

LOWERING OF FREEZING POINTS BY SALTS IN SOLUTION

g. mol / 1000 g. H_2O	Molecular Lowering.
$CdBr_2$, 272.3: 3, 14.	
0.00324	5.1°
.00718	4.6
.03627	3.84
.0719	3.39
.1122	3.18
.220	2.96
.440	2.76
.800	2.59
$CuBr_2$, 223.5: 9.	
0.0242	5.1°
.0817	5.1
.2255	5.27
.6003	5.89
$CaBr_2$, 200.0: 14.	
0.0871	5.1°
.1742	5.18
.3484	5.30
.5226	5.64
$MgBr_2$, 184.28: 14.	
0.0517	5.4°
.103	5.16
.207	5.26
.517	5.85
KBr, 119.1: 9, 21.	
0.0305	3.61°
.1850	3.49
.6801	3.30
.250	3.78
.500	3.56
CdI_2, 366.1: 3, 5, 22	
0.00210	4.5°
.00626	4.0
.02062	3.52
.04857	2.70
.1360	2.35
.333	2.13
.684	2.23
.888	2.51
KI, 166.0: 9, 2.	
0.0651	3.5°
.2782	3.50
.6030	3.42
1.003	3.37
SrI_2, 341.3: 22.	
0.054	5.1°
.108	5.2
.216	5.35
.327	5.52
NaOH, 40.06: 15	
0.02002	3.45°
.05005	3.45
.1001	3.41
.2000	3.407

g. mol. / 1000 g. H_2O	Molecular Lowering.
KOH, 56.16: 1, 15, 23.	
0.00352	3.60°
.00770	3.59
.02002	3.44
.05006	3.43
.1001	3.42
.2003	3.424
.230	3.50
.465	3.57
CH_3OH, 32.03: 24, 25.	
0.0100	1.80°
.0301	1.82
.2018	1.811
1.046	1.86
3.41	1.88
6.200	1.944
C_2H_5OH, 46.04: 1, 12, 17, 24-27	
0.000402	1.67°
.004993	1.67
.0100	1.81
.02892	1.707
.0705	1.85
.1292	1.829
.2024	1.832
.5252	1.834
1.0891	1.826
1.760	1.83
3.901	1.92
7.91	2.02
11.11	2.12
18.76	1.81
0.0173	1.80
.0778	1.79
K_2CO_3, 138.30: 6	
0.0100	5.1°
.0200	4.93
.0500	4.71
.100	4.54
.200	4.39
Na_2CO_3, 106.10: 6.	
0.0100	5.1°
.0200	4.93
.0500	4.64
.1000	4.42
.2000	4.17
Na_2SO_3, 126.2: 28	
0.1044	4.51°
.3397	3.74
.7080	3.38
Na_2HPO_4, 142.1: 22, 29	
0.01001	5.0°
.02003	4.84
.05008	4.60
.1002	4.34

g. mol / 1000 g. H_2O	Molecular Lowering.
Na_2SiO_3, 122.5: 15.	
0.01052	6.4°
.05239	5.86
.1048	5.28
.2099	4.66
.5233	3.99
HCl, 36.46: 1-3, 6, 13, 18, 22.	
0.00305	3.68°
.00695	3.66
.0100	3.6
.01703	3.59
.0500	3.59
.1025	3.56
.2000	3.57
.3000	3.612
.464	3.68
.516	3.79
1.003	3.95
1.032	4.10
1.500	4.42
2.000	4.97
2.115	4.52
3.000	6.03
3.053	4.90
4.065	5.67
4.657	6.19
HNO_3, 63.05: 3, 13, 15.	
0.02004	3.55°
.05015	3.50
.0510	3.71
.1004	3.48
.1059	3.53
.2015	3.45
.250	3.50
500	3.62
1.000	3.80
2.000	4.17
3.000	4.64
H_3PO_2, 66.0: 29.	
0.1260	2.90°
.2542	2.75
.5171	2.59
1.071	2.45
H_3PO_3, 82.0: 4, 5.	
0.0745	3.0°
.1241	2.8
.2482	2.6
1.00	2.39
H_3PO_4, 98.0: 6, 22	
0.0100	2.80°
.0200	2.68
.0500	2.49
.1000	2.36
.2000	2.25

g. mol. / 1000 g. H_2O	Molecular Lowering.
0.472	2.20°
.944	2.27
1.620	2.60
$(COOH)_2$, 90.02: 4, 15.	
0.01002	3.3°
.02005	3.19
.05019	3.03
.1006	2.83
.2022	2.64
.366	2.56
.648	2.3
$C_3H_5(OH)_3$, 92.06: 24, 25.	
0.0200	1.86°
.1008	1.86
.2031	1.85
.535	1.91
2.40	1.98
5.24	2.13
$(C_2H_5)_2O$, 74.08: 24	
0.0100	1.6°
.0201	1.67
.1011	1.72
.2038	1.702
Dextrose, 180.1: 24, 30.	
0.0198	1.84°
.0470	1.85
.1326	1.87
.4076	1.894
1.102	1.921
Levulose, 180.1: 24, 25	
0.0201	1.87°
.2050	1.871
.554	2.01
1.384	2.32
2.77	3.04
$C_{12}H_{22}O_{11}$, 342.2: 1, 24, 26.	
0.000332	1.90°
.001410	1.87
.009978	1.86
.0201	1.88
.1305	1.88
H_2SO_4, 98.08: 13, 20, 31-33.	
0.00461	4.8°
.0100	4.49
.0200	4.32
.0461	4.10
.100	3.96
.200	3.85
.400	3.98
1.000	4.19
1.500	4.96
2.000	5.65
2.500	6.53

1-20 *See* page 217.
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RISE OF BOILING POINT PRODUCED BY SALTS DISSOLVED IN WATER

This table gives the number of grams of the salt which, when dissolved in 100 grams of water, will raise the boiling point by the amount stated in the headings of the different columns. The pressure is supposed to be 76 centimeters.

Salt	1 °C	2°	3	4	5	7	10	15°	20	25
$BaCl_2 + 2H_2O$	15.0	31.1	47.3	63.5	(71.6 gives 4°.5 rise of temp.)					
$CaCl_2$	6.0	11.5	16.5	21.0	25.0	32.0	41.5	55.5	69.0	84.5
$Ca(NO_3)_2 + 2H_2O$	12.0	25.5	39.5	53.5	68.5	101.0	152.5	240.0	331.5	443.5
KOH	4.7	9.3	13.6	17.4	20.5	26.4	34.5	47.0	57.5	67.3
$KC_2H_3O_2$	6.0	12.0	18.0	24.5	31.0	44.0	63.5	98.0	134.0	171.5
KCl	9.2	16.7	23.4	29.9	36.2	48.4	(57.4 gives a rise of 8°.5)			
K_2CO_3	11.5	22.5	32.0	40.0	47.5	60.5	78.5	103.5	127.5	152.5
$KClO_3$	13.2	27.8	44.6	62.2						
KI	15.0	30.0	45.0	60.0	74.0	99.5	134.	185.0	(220 gives 18°.5)	
KNO_3	15.2	31.0	47.5	64.5	82.0	120.5	188.5	338.5		
$K_2C_4H_4O_6 + \frac{1}{2}H_2O$	18.0	36.0	54.0	72.0	90.0	126.5	182.0	284.0		
$KNaC_4H_4O_6$	17.3	34.5	51.3	68.1	84.8	119.0	171.0	272.5	390.0	510.0
$KNaC_4H_4O_6 + 4H_2O$	25.0	53.5	84.0	118.0	157.0	266.0	554.0	5510.0		
$LiCl$	3.5	7.0	10.0	12.5	15.0	20.0	26.0	35.0	42.5	50.0
$LiCl + 2H_2O$	6.5	13.0	19.5	26.0	32.0	44.0	62.0	92.0	123.0	160.5
$MgCl_2 + 6H_2O$	11.0	22.0	33.0	44.0	55.0	77.0	110.0	170.0	241.0	334.5
$MgSO_4 + 7H_2O$	41.5	87.5	138.0	196.0	262.0					
$NaOH$	4.3	8.0	11.3	14.3	17.0	22.4	30.0	41.0	51.0	60.1
$NaCl$	6.6	12.4	17.2	21.5	25.5	33.5	(40.7 gives 8°.8 rise)			
$NaNO_3$	9.0	18.5	28.0	38.0	48.0	68.0	99.5	156.0	222.0	
$NaC_2H_3O_2 + 3H_2O$	14.9	30.0	46.1	62.5	79.7	118.1	194.0	480.0	6250.0	
$Na_2S_2O_3$	14.0	27.0	39.0	49.5	59.0	77.0	104.0	152.0	214.5	311.0
Na_2HPO_4	17.2	34.4	51.4	68.4	85.3					
$Na_2C_4H_4O_6 + 2H_2O$	21.4	44.4	68.2	93.9	121.3	183.0	(237.3 gives 8°.4 rise)			
$Na_2S_2O_3 + 5H_2O$	23.8	50.0	78.6	108.1	139.3	216.0	400.0	1765.0		
$Na_2CO_3 + 10H_2O$	34.1	86.7	177.6	369.4	1052.9					
$Na_2B_4O_7 + 10H_2O$	39.	93.2	254.2	898.5	(5555.5 gives 4°.5 rise)					
NH_4Cl	6.5	12.8	19.0	24.7	29.7	39.6	56.2	88.5		
NH_4NO_3	10.0	20.0	30.0	41.0	52.0	74.0	108.0	172.0	248.0	337.0
$(NH_4)_2SO_4$	15.4	30.1	44.2	58.0	71.8	99.1	(115.3 gives 108.2)			
$SrCl_2 + 6H_2O$	20.0	40.0	60.0	81.0	103.0	150.0	234.0	524.0		
$Sr(NO_3)_2$	24.0	45.0	63.6	81.4	97.6					
$C_4H_6O_6$	17.0	34.4	52.0	70.0	87.0	123.0	177.0	272.0	374.0	484.0
$C_2H_2O_4 + 2H_2O$	19.0	40.0	62.0	86.0	112.0	169.0	262.0	540.0	1316.0	50000.0
$C_6H_8O_7 + H_2O$	29.0	58.0	87.0	116.0	145.0	208.0	320.0	553.0	952.0	

Salt	40°	60°	80°	100°	120	140°	160°	180°	200	240°
$CaCl_2$	137.5	222.0	314.0							
KOH	92.5	121.7	152.6	185.0	219.8	263.1	312.5	375.0	444.4	623.0
$NaOH$	93.5	150.8	230.0	345.0	526.3	800.0	1333.0	2353.0	6452.0	–
NH_4NO_3	682.0	1370.0	2400.0	4099.0	8547.0	∞				
$C_4H_6O_6$	980.0	3774.0	(infinity gives 170)							

* Compiled from a paper by Gerlach, "Zeit. f. Anal. Chem." vol. 26.

TABLE 249

FREEZING MIXTURES *

Column 1 gives the name of the principal refrigerating substance, *A* the proportion of that substance, *B* the proportion of a second substance named in the column, *C* the proportion of a third substance, *D* the temperature of the substances before mixture, *E* the temperature of the mixture, *F* the lowering of temperature, *G* the temperature when all snow is melted, when snow is used, and *H* the amount of heat absorbed in heat units (small calories when *A* is grams). Temperatures are in Centigrade degrees.

Substance.	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
$NaC_2H_3O_2$ (cryst.)	85	H_2O–100	–	10.7	−4.7	15.4	–	–
NH_4Cl . . .	30	" "	–	13.3	−5.1	18.4	–	–
$NaNO_3$ . . .	75	" "	–	13.2	−5.3	18.5	–	–
$Na_2S_2O_3$ (cryst.) .	110	" "	–	10.7	−8.0	18.7	–	–
KI	140	" "	–	10.8	−11.7	22.5	–	–
$CaCl_2$ (cryst.) .	250	" "	–	10.8	−12.4	23.2	–	–
NH_4NO_3 . .	60	" "	–	13.6	−13.6	27.2	–	–
$(NH_4)_2SO_4$ . .	25	" 50	NH_4NO_3–25	–	–	26.0	–	–
NH_4Cl . . .	25	" "	" "	–	–	22.0	–	–
$CaCl_2$ . . .	25	" "	" "	–	–	20.0	–	–
KNO_3 . . .	25	" "	NH_4Cl–25	–	–	20.0	–	–
Na_2SO_4 . .	25	" "	" "	–	–	19.0	–	–
$NaNO_3$ . . .	25	" "	" "	–	–	17.0	–	–
K_2SO_4 . . .	10	Snow 100	–	−1	−1.9	0.9	–	
Na_2CO_3 (cryst.) .	20	" "	–	−1	−2.0	1.0	–	–
KNO_3 . . .	13	" "	–	−1	−2.85	1.85	–	–
$CaCl_2$ . . .	30	" "	–	−1	−10.9	9.9	–	–
NH_4Cl . . .	25	" "	–	−1	−15.4	14.4	–	–
NH_4NO_3	45	" "	–	−1	−16.75	15.75	–	–
$NaNO_3$ . . .	50	" "	–	−1	−17.75	16.75	–	–
NaCl . . .	33	" "	–	−1	−21.3	20.3	–	–
$H_2SO_4 + H_2O$ (66.1 % H_2SO_4)	1	" 1.097	–	−1	−37.0	36.0	−37.0	0.0
	1	" 1.26	–	−1	−36.0	35.0	−30.2	17.0
	1	" 1.38	–	−1	−35.0	34.0	−25.0	27.0
	1	" 2.52	–	−1	−30.0	29.0	−12.4	133.0
	1	" 4.32	–	−1	−25.0	24.0	−7.0	273.0
	1	" 7.92	–	−1	−20.0	19.0	−3.1	553.0
	1	" 13.08	–	−1	−16.0	15.0	−2.1	967.0
$CaCl_2 + 6H_2O$	1	" 0.35	–	0	–	–	0.0	52.1
	1	" .49	–	0	–	–	−19.7	49.5
	1	" .61	–	0	–	–	−39.0	40.3
	1	" .70	–	0	–	–	−54.9†	30.0
	1	" .81	–	0	–	–	−40.3	46.8
	1	" 1.23	–	0	–	–	−21.5	88.5
	1	" 2.46	–	0	–	–	−9.0	192.3
	1	" 4.92	–	0	–	–	−4.0	392.3
Alcohol at 4°	77	" 73	–	0	−30.0	–	–	–
	–	CO_2 solid	–	–	−72.0	–	–	–
Chloroform . .	–	" "	–	–	−77.0	–	–	–
Ether . . .	–	" "	–	–	−77.0	–	–	–
Liquid SO_2 . .	–	" "	–	–	−82.0	–	–	–
NH_4NO_3 .	1	H_2O–.75	–	20	5.0	–	–	33.0
	1	" .94	–	20	−4.0	–	–	21.0
	1	" "	–	10	−4.0	–	–	34.0
	1	" "	–	5	−4.0	–	–	40.5
	1	Snow "	–	0	−4.0	–	–	122.2
	1	H_2O–1.20	–	10	−14.0	–	–	17.9
	1	Snow "	–	0	−14.0	–	–	129.5
	1	H_2O–1.31	–	10	−17.5†	–	–	10.6
	1	Snow "	–	0	−17.5†	–	–	131.9
	1	H_2O–3.61	–	10	−8.0	–	–	0.4
	1	Snow "		0	−8.0	–	–	327.0

* Compiled from the results of Cailletet and Colardeau, Hammerl, Hanamann, Moritz, Pfaundler, Rudorf, and Tollinger.
† Lowest temperature obtained.

Table 250

CRITICAL TEMPERATURES, PRESSURES, AND DENSITIES OF GASES

Substance	θ	P	d	Ref.
Acetylene	36	62	0.231	1
Air	−140.7	37.2	.35 (a)	1
			.31 (b)	1
Alcohol (C_2H_6O)	243.1	63.1	.2755	6, 7
Alcohol (CH_4O)	240.0	78.7	.272	7, 8
Allylene	128	....	....	1
Ammonia	132.4	111.5	.235	1
Argon	−122	48	.531	1
Benzene	288.5	47.7	.304	9
Bromine	302	....	....	9
iso-Butane	134	37	....	1
n-Butane	153	36	....	1
Carbon dioxide	31.1	73.0	.4681	1, 2
Carbon disulphide	273	76	....	9
Carbon monoxide	−139	35	.311	1
Chlorine	144.0	76.1	.573	1
Chloroform	263	....	.516	9
Cyanogen	128	59	....	1
Ethane	32.1	48.8	.21?	1
Ether (ethyl)	193.8	35.5	.2625	10, 11
Ethyl chloride	187.2	52	.33	1
Ethylene	9.7	50.9	.2159	1, 3
Helium	−267.9	2.26	.0693	1
Hydrogen	−239.9	12.8	.0310	1
Hydrogen bromide	90	84	....	1
Hydrogen chloride	51.4	81.6	.42	1
Hydrogen iodide	151	82	....	1
Hydrogen sulphide	100.4	88.9	....	1
Krypton	− 63?	54?	.78?	1
Methane	− 82.5	45.8	.162	1
Methyl chloride	143.1	65.8	.37?	1
Neon	−228.7	25.9	.484	1
Nitric oxide	− 94?	65	.52?	1
Nitrogen	−147.1	33.5	.3110	1
Nitrous oxide	36.5	71.7	.45?	1
Oxygen	−118.8	49.7	.430	1
Phosgene	182	56	.52	1
Propane	95.6	43	....	1
Propylene	92.3	45.0	....	1
Sulphur dioxide	157.4	77.8	.5240	1, 4, 5
Water	374.0	217.7	.4	9
Xenon	16.6	58.2	1.155	1

(a) "Plait point."
(b) "Critical point of contact."

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(Table prepared by Gas Chemistry Section, Bur. Standards, Feb. 19, 1929.)

Table 251

THERMAL CONDUCTIVITY, METALS AND ALLOYS

The coefficient k is the quantity of heat in small calories which is transmitted per second through a plate one centimeter thick per square centimeter of its surface when the difference of temperature between the two faces of the plate is one degree Centigrade. The coefficient k is found to vary with the absolute temperature of the plate, and is expressed approximately by the equation $k_t = k_0[1 + \alpha(t - t_0)]$. k_0 is the conductivity at t_0, the lower temperature of the bracketed pairs in the table, k_t that at temperature t, and α is a constant. k_t in g-cal. per degree C per sec. across cm cube = $0.239 \times k_t$ in watts per degree C per sec. across cm cube.

Substance	t°C	k_t	α	Reference.
Aluminum	−160	0.514	—	1
"	18	0.480	+.0030	2
"	100	0.492		
"	200	0.545	+.0020	3
"	400	0.760		
"	500	0.885	+.0014	3
"	600	1.01		
Antimony	0	0.0442	−.00104	4
"	100	0.0396		
Bismuth	−186	0.025	—	5
"	18	0.0194	−.0021	2
"	100	0.0161		
Brass	−160	0.181	—	1
"	17	0.260	—	1
", yellow	0	0.204	+.0024	4
", red	0	0.246	+.0015	4
Cadmium, pure	−160	0.239	—	1
" "	18	0.222	−.00038	2
"	100	0.215		
Constantan	18	0.0540	+.00227	2
(60 Cu+40 Ni)	100	0.0640		
Copper,* pure	−160	1.079	—	1
" "	18	0.918	−.00013	2
" "	100	0.908		
German silver	0	0.070	+.0027	4
Gold	17	0.705	−.00007	6
Graphite	17	0.037	+.0003	6
Iridium	17	0.141	−.0005	8
Iron,† pure	18	0.161	−.0008	2
" "	100	0.151		
Iron, wrought	−160	0.152	—	1
" "	18	0.144	−.00008	2
" "	100	0.143		
" steel, 1%	18	0.108	−.0001	2
C	100	0.107		
Lead, pure	−160	0.092	—	1
" "	18	0.083	−.0001	2
" "	100	0.081		
Magnesium	0 to 100	0.376	—	4
Manganin	−160	0.035	—	1
" (84 Cu+4	18	0.0519	+.0026	2
Ni 12 Mn)	100	0.0630		
Mercury	0	0.0148	+.0055	7
"	50	0.0189		
Molybdenum	17	0.346	−.0001	6
Nickel	−160	0.129	—	1
"	18	0.1420	—	2
"	0	0.1425	−.00032	3
"	100	0.1380		
"	200	0.1325	−.00095	3
"	700	0.069		
"	1000	0.064	−.00047	3
"	1200	0.058		
Palladium	18	0.1683	+.0010	2
"	100	0.182		
Platinum	18	0.1664	+.00051	2
"	100	0.1733		
Pt 10% Ir	17	0.074	+.0002	6
Pt 10% Rh	17	0.072	+.0002	6
Platinoid	18	0.060	—	1
Potassium	5.0	0.232	−.0013	8
"	57.4	0.216		
Rhodium	17	0.210	−.0010	6
Silver, pure	−160	0.998	—	1
"	18	1.006	−.00017	2
"	100	0.992		
Sodium	5.7	0.321	−.0012	8
"	88.1	0.288		
Tantalum	17	0.130	−.0001	6
"	1700	0.174	—	9
"	1900	0.186	+.00032	9
"	2100	0.198		
Tin	0	0.155	−.00069	4
"	100	0.145		
", pure	−160	0.192	—	1
Tungsten	17	0.476	−.0001	6
Tungsten	1600	0.249	+.00023	10
"	2000	0.272		
"	2400	0.294	+.00016	10
"	2800	0.313		
Wood's alloy	—	0.319	—	7
Zinc, pure	−160	0.278	—	1
" "	18	0.2653	−.00016	2
" "	100	0.2619		

References: (1) Lees, Phil. Trans. 1908; (2) Jaeger and Diesselhorst, Wiss. Abh. Phys. Tech. Reich. 3, 1900; (3) Angell, Phys. Rev. 1911; (4) Lorenz; (5) Macchia, 1907; (6) Barratt, Pr. Phys. Soc. 1914; (7) H. F. Weber, 1879; (8) Hornbeck, Phys. Rev. 1913; (9) Worthing, Phys. Rev. 1914; (10) Worthing, Phys. Rev. 1917.

* Copper: 100–197° C, k_t = 1.043; 100–268°, 0.969; 100–370°, 0.931; 100–541°, 0.902 (Hering; for reference see next page).

† Iron: 100–727° C, k_t = 0.202; 100–912°, 0.184; 100–1245°, 0.191 (Hering).

TABLE 252.—Thermal Conductivity of Insulators at High Temperatures

(See also Table 251 for metals; k in gram-calories per degree centigrade per second across a centimeter cube.)

Material.	Temperature, ° C	k	Reference.	Material.	Temperature, ° C	k	Reference
Amorphous carbon . . .	37–163	.028–.003	1	Brick: Carborundum	150–1200	.0032–.027	3
	170–330	.027–.004	1	Building, Terra-cotta	15–1100	.0018–.0038	3
	240–523	.020–.003	1				
	283–597	.011–.004	1	Fire-clay	125–1220	.0032–.0054	3
	100–360	.089	2	Gas-retort . . .	100–1125	.0038	3
	100–751	.124	2	Graphite	300–700	.024	3
	100–842	.129	2	Magnesia	50–1130	.0027–.0072	3
Graphite (artificial) . . .	100–390	.338	2	Silica	100–1000	.002 –.0033	3
	100–546	.324	2	Granite	100	.0045–.0050	4
	100–720	.306	2		200	.0043–.0097	4
	100–914	.291	2		500	.0040	4
	30–2830	.162	1	Limestone	40	.0046–.0057	4
	2800–3200	.002	1		100	.0039–.0049	4
	90–110	.55–.45	1		350	.0032–.0035	4
	180–120	.44–.34	1	Porcelain (Sèvres) . .	165–1055	.0039–.0047	3
	500–700	.31–.22	1	Stoneware mixtures .	70–1000	.0029–.0053	3

References: (1) Hansen, Tr. Am. Electrochem. Soc. 16, 329, 1909; (2) Hering, Tr. Am. Inst. Elect. Eng. 1910; (3) Bul. Soc. Encouragement, 111, 879, 1909; Electroch. and Met. Ind. 7, 383, 433, 1909; (4) Poole, Phil. Mag. 24, 45, 1912; see also Clement, Egy, Eng. Exp. Univers. Ill. Bull. 36, 1909; Dewey, Progressive Age, 27, 772, 1909; Woolson, Eng. News, 58, 166, 1907, heat transmission by concretes; Richards, Met. and Chem. Eng. 11, 575, 1913. The ranges in values under 1 do not depend on variability in material but on possible errors in method; reduced from values expressed in other units.

TABLE 253.—Thermal Conductivity of Various Substances

Substance, temperature.	k_t	Reference.	Substance, temperature.	k_t	Reference.
Aniline BP 183° C, −160	.000112	1	Naphthalene MP 79° C, −160	.0013	1
Carbon, gas	.010	–	Naphthalene MP 79° C, 0	.00081	1
Carbon, graphite	.012	–	Naphthol — β, MP 122° C, −160 . .	.00068	1
Carborundum	.00050	2	Naphthol, 0	.00062	1
Concrete, cinder	.00081	–	Nitrophenol, MP 114° C, −160	.00106	1
stone	.0022	3	Nitrophenol, 0	.00065	1
Diatomaceous earth	.00013	4	Paraffin MP 54° C, −160	.00062	1
Earth's crust	.004	–	Paraffin, 0	.00059	1
Fire-brick	.00028	4	Porcelain	.0025	–
Fluorite, −190	.093	5	Quartz ⊥ to axis, −190	.0586	5
Fluorite, 0	.025	5	" , 0	.0173	5
Glass: window	.0025	–	" , 100	.0133	5
crown, O3572, −190	.00118	5	Quartz ∥ to axis, 0	.0325	5
crown, O3572, 0	.00280	5	Rock salt, 0	.0167	5
crown, O3572, 100	.00324	5	Rock salt, 30	.0150	5
h'vy flint O165, −190	.00081	5	Rubber, vulcanized, −160	.00033	5
h'vy flint O165, 0	.00170	5	Rubber, 0	.00037	5
h'vy flint O165, 100	.00181	5	Rubber, para	.00045	–
Glycerine, −160	.00077	1	Sand, white, dry	.00093	6
Granite	.0053	6	Sandstone, dry	.0055	6
Ice, −160	.0066	1	Sawdust	.00012	–
Ice, 0	.0050	1	Slate ⊥ to cleavage	.0034	6
Iceland spar, −190	.038	5	Slate ∥ to cleavage	.0060	6
Iceland spar, 0	.0103	5	Snow, fresh, dens. = 0.11	.00026	7
Lime	.00029	4	Snow, old	.0012	7
Limestones, calcite	.0047 to	6	Soil, average, sl't moist	.0037	–
Marbles, dolomite	.0056	6	Soil, very dry	.0037	–
Mica	.0018	–	Sulphur, rhombic, 0	.00070	5
Flagstone ⊥ to cleavage	.0063	6	Vaseline, 20	.00022	8
Micaceous ∥ to cleavage	.0044	6	Vulcanite	.00087	9

References: (1) Lees, Tr. R. S. 1905; (2) Lorenz; (3) Norton; (4) Hutton, Blard; (5) Eucken, Ann. d. Phys., 1911; (6) Herschel, Lebour, Dunn, B. A. Committee, 1879; (7) Jansson, 1904; (8) Melmer, 1911; (9) Stefan.

TABLE 254

THERMAL CONDUCTIVITY OF INSULATING MATERIALS

(Compiled from the International Critical Tables, which see for more complete data.)

No.	Material	Density g/cm³	t°C	Conductivity joule/cm²/sec.	Conductivity g-cal./cm²/sec.
1	Air, 76 cm Hg	.00129	0	.00023	.000055
2	Asbestos wool	.40	−100	.00068	.000162
3	" "	.40	0	.00090	.000215
4	" "	.40	+100	.00101	.00024
5	" with 85 per cent MgO	.3	30	.00075	.000179
6	Brick, very porous, dry	.71	20	.00174	.00042
7	" machine made, dry	1.54	0	.00038	.000091
8	" " " moist 1.2% vol.		50	.00096	.00023
9	Calorox, fluffy mineral matter	.064	30	.00032	.000076
10	Celluloid, white	1.4	30	.00021	.000050
11	Cement mortar	2.0	90	.0055	.0013
12	Chalk			.0092	.0022
13	Charcoal	.18	20	.00055	.00013
14	Coke dust	1.0	20	.0015	.00036
15	Concrete	1.6	0	.008	.002
16	Cork	.05	0	.00032	.000076
17	"	.05	100	.00041	.000098
18	"	.35	0	.00061	.000146
19	"	.35	100	.00079	.000189
20	Cotton, tightly packed	.08	−150	.00038	.000091
21	" " "	.08	0	.00056	.000133
22	" " "	.08	+150	.00076	.00018
23	Cotton wool, tightly packed	.08	30	.00042	.00010
24	Diatomite, (binders may increase 100%)	.20	0	.00052	.00012
25	Diatomite, ditto	.20	400	.00094	.00022
26	" "	.50	0	.00086	.00021
27	" "	.50	400	.00157	.00037
28	Ebonite	1.19	−190	.00138	.00033
29	"	1.19	− 78	.00157	.00038
30	"	1.19	0	.00160	.00038
31	Felt, flax fibers	.18	30	.00047	.00011
32	" hair	.27	30	.00036	.000086
33	" wool	.15	40	.00063	.000151
34	" "	.33	30	.00052	.000124
35	Fuller's earth	.53	30	.00101	.00024
36	Glass, lead		15	.0060	.00143
37	" soda	2.59	20	.0072	.00172
38	" "	2.59	100	.0076	.00182
39	" wool	.22	50	.00042	.000100
40	" "	.22	100	.00050	.000120
41	" "	.22	200	.00065	.000155
42	" "	.22	300	.00081	.000195
43	Graphite, 100 mesh	.48	40	.0018	.00044
44	" 40 "	.42	40	.0038	.00093
45	" 20 to 40 mesh	.70	40	.0129	.0031
46	Horsehair, compressed	.17	20	.00051	.000122
47	Ice	.92	0	.022	.0053
48	Leather, chamois		85	.00063	.000151
49	" cowhide		85	.00176	.000421
50	" sole	1.0	30	.0016	.00038
51	Linen		20	.00086	.00021
52	Linoleum, cork	.54	20	.00080	.000191
53	Mica, average		50	.0050	.0012

THERMAL CONDUCTIVITY OF INSULATING MATERIALS

No.	Material	Density g/cm³	t°C	Conductivity joule/cm²/sec.	Conductivity g-cal./cm²/sec.
54	Micanite		30	.0021–.0042	.000050–.00010
55	Mineral wool	.15	30	.00042	.00010
56	" "	.30		.00052	.00012
57	Paper, rice		40	.00046	.00011
58	" blotting		20	.00063	.00015
59	Paraffin wax	.89	30	.0023	.00055
60	Peat, dry	.19	30	.00052	.00012
61	" blocks	.84	20	.0017	.00041
62	Porcelain		90	.0104	.0025
63	Rubber, rigid sponge, hard	.09	25	.00037	.000088
64	" sponge, vulcanized	.22	20	.00054	.00013
65	" commercial, 40% rubber		25	.0028	.00067
66	" " 92% "		25	.0016	.00038
67	Sawdust	.20	30	.00060	.000143
68	Shellac			.0023	.0006
69	Silk			.00040	.00010
70	" scrap from spinning mill	.10	−200	.00023	.000055
71	" " " " "	.10	−100	.00037	.000088
72	" " " " "	.10	0	.000495	.000118
73	" " " " "	.10	50	.00056	.000134
74	Snow	.25	0	.0016	.00038
75	Steel wool	.15	55	.00080	.000191
76	" "	.08	55	.00090	.00022
77	Wool, pure	.09	30	.00036	.000086
78	" " very loose packing	.04	30	.00042	.00010
79	Woods: Ash ⊥ to grain	.74	20	.0017	.00041
80	" ‖ " "	.74	20	.0031	.00074
81	Balsa ⊥ to grain	.11	30	.00045	.000084
82	Boxwood	.90	20	.0015	.00036
83	Cedar ⊥ to grain	.48		.0011	.00027
84	Cypress ⊥ to grain	.46	30	.00096	.00023
85	Fir ⊥ to grain	.54	20	.0014	.00033
86	" ‖ to grain	.54	20	.0035	.00081
87	Lignum vitae	1.16	20	.0025	.00060
88	" "	1.16	100	.0030	.00072
89	Mahogany, ⊥ to grain	.70	20	.0016	.00038
90	" ‖ to grain	.70	20	.0031	.00074
91	Oak, ⊥ to grain	.82	15	.0021	.00050
92	" ‖ to grain	.82	15	.0036	.00086
93	Pine, pitch, ⊥ to grain		30	.0015	.00036
94	" Virginia, ditto	.55	30	.0014	.00033
95	" white, ditto	.45	60	.0011	.00026
96	" " ‖ to grain	.45	60	.0026	.00062
97	Spruce, ⊥ to grain	.41		.0011	.00026
98	Teak, ⊥ to grain	.64	15	.00175	.00042
99	" ‖ to grain	.64	15	.0038	.00091
100	Walnut, ⊥ to grain	.65	20	.0014	.00033
101	Rocks: Basalt		20	.020	.0048
102	Chalk			.0092	.0022
103	Granite	2.8		.022	.0053
104	Limestone, very variable	2.0	20	.010	.0024
105	Slate, ⊥ to cleavage		95	.014	.0033
106	" ‖ to cleavage		95	.025	.0060
107	Sandstone, air-dried	2.2	20	.013	.00031
108	" freshly cut	2.3	20	.017	.00041

Running numbers arranged in order of increasing conductivity at room temperatures: **.0002:** 10, 1, 16, 9, 32, 77, 7, 63, 69, 30, 55, 78, 81, 37, 31, 50, 72, 81; **.0005:** 46, 24, 56, 34, 60, 64, 13, 21, 67, 18, 33, 58; **.00075:** 5, 52, 26, 51, 3, 76, 84; **.001:** 35, 83, 97, 85, 94, 100, 14, 82, 93, 30, 50, 66, 74, 89, 61, 79, 6, 43, 98, 54, 91, 59, 68; **.0025:** 87, 65, 80, 90, 86, 44, 36, 92, 99, 54; **.005:** 53, 36, 37, 15, 12, 102; **.010:** 104, 45, 107, 108, 101, 47, 103.

TABLE 255.—Thermal Conductivity of Various Insulators

k_t is the heat in gram-calories flowing in 1 sec. through a plate 1 cm thick per sq. cm for 1°C drop in temperature.

Substance.	Density.	°C	k_t
Asbestos fiber	0.201	500	.00019
85% magnesia asbestos	.216	100	.00016
		500	.00017
Cotton	.021	100	.000111
"	.101	"	.000071
Eiderdown	.0021	150	.00015
"	.109	"	.000046
Lampblack, Cabot number 5	.193	100	.000074
		500	.000107
Quartz, mesh 200	1.05	500	.00024
Poplox, popped Na_2SiO_3	0.093	200	.000091
		500	.000160
Wool fibers	.015	100	.000118
" "	.054	"	.000085
" "	.192	"	.000054

Substance.	k_t	Authority.
Asbestos paper	0.00043	Lees-Chorlton.
Blotting paper	.00015	
Portland cement	.00071	
Cork, t, 0°C	.0007?	Forbes.
Chalk	.0020	H, L, D, see p. 205.
Ebonite, t, 49°	.00037	
Glass, mean	.002	Various.
Ice	.0057	Neumann.
Leather, cow-hide	.00042	Lees-Chorlton.
" chamois	.00015	
Linen	.00021	
Silk	.000095	
Caen stone, limestone	.0043	H, L, D.
Free stone, sandstone	.0021	

Left-hand half of table from Randolph, Tr. Am. Electroch. Soc. XXI., p. 550, 1912; k_t (Randolph's values) is mean conductivity between given temperature and about 10°C. Note effect of compression (density). The following are from Barratt Proc. Phys. Soc., London, 27, 81, 1914.

Substance.	Density.	k_t at 20°C	k_t at 100°C	Substance.	Density.	k_t at 20°C	k_t at 100°C
Brick, fire	1.73	.00110	.00109	Boxwood	0.90	.00036	.00041
Carbon, gas	1.42	.0085	.0095	Greenheart	1.08	.00112	.00110
Ebonite	1.19	.00014	.00013	Lignumvitæ	1.16	.00060	.00072
Fiber, red	1.29	.00112	.00119	Mahogany	0.55	.00051	.00060
Glass, soda	2.59	.00172	.00182	Oak	0.65	.00058	.00061
Silica, fused	2.17	00237	.00255	Whitewood	0.58	.00041	.00045

The following values are from unpublished data furnished by C. E. Skinner of the Westinghouse Co., Pittsburgh, Penn. They give the mean conductivity in gram-calories per sec. per cm cube per °C when the mean temperature of the cube is that stated in the table. Resistance in thermal ohms (watts/inch²/inch/°C) $= \frac{1}{10.6}$ conductivity.

Substance.	Grams. per cm³	Conductivity. 100° C	200° C	300° C	400° C	500° C	Safe temp.
Air-cell asbestos	0.232	0.00034	0.00043	0.00050	—	—	320
Cork, ground	.168	.00015	.00019	—	—	—	180
Diatomit	.326	.00028	.00032	.00037	0.00042	0.00046	600
Infusorial earth, natural	.506	.00034	.00032	.00040	—	—	
" " h'd pressed blocks	.321	.00030	.00029	.00033	.00036	—	400
Magnesium carbonate	.450	.00023	.00025	.00025	—	—	300
Vitribestos	.362	.00049	.00066	.00079	.00090	.00102	600

TABLE 256.—Thermal Conductivity of Water and Salt Solutions

Substance.	°C	k_t	Authority.
Water	0	0.00150	Goldschmidt, '11.
	11	.00147	Lees, '98.
	25	.00136	
	20	.00143	Milner, Chattock, '98

Solution in water.	Density.	°C	k_t	Authority.
$CuSO_4$	1.160	4.4	0.00118	H. F. Weber.
KCl	1.026	13.	.00116	Graetz.
NaCl	1.178	4.4	.00115	H. F. Weber.
"	—	26.3	.00135	
H_2SO_4	1.054	20.5	.00126	Chree.
"	1.180	21.	.00130	
$ZnSO_4$	1.134	4.5	.00118	H. F. Weber.
"	1.136	4.5	.00115	

TABLE 257.—Thermal Conductivity of Organic Liquids

Substance.	°C	k_t	Refer.	Substance.	°C	k_t	Refer.	Substance.	°C	k_t	Refer.
Acetic acid	9–15	$.0_3472$	1	Carbon disulphide	0	$.0_3387$	3	Oils: olive	—	$.0_3395$	4
Alcohols: methyl	11	$.0_352$	2	Chloroform	9–15	$.0_3288$	1	" castor	—	$.0_3425$	4
" ethyl	11	$.0_346$	2	Ether	9–15	$.0_3303$	1	Toluene	0	$.0_3349$	3
" amyl	0	$.0_3345$	3	Glycerine	25	$.0_368$	2	Vaseline	25	$.0_344$	2
Aniline	0	$.0_3434$	–	Oils: petroleum	13	$.0_3355$	5	Xylene	0	$.0_3343$	3
Benzene	9–15	$.0_3333$	1	" turpentine	13	$.0_3325$	5				

References: (1) H. F. Weber; (2) Lees; (3) Goldschmidt; (4) Wachsmuth; (5) Graetz.

TABLE 258.—Thermal Conductivity of Gases

The conductivity of gases, $k_t = \frac{1}{4}(9\gamma - 5)\mu C_v$, where γ is the ratio of the specific heats, C_p/C_v, and μ is the viscosity coefficient (Jeans, Dynamical Theory of Gases, 1916). Theoretically k_t should be independent of the density and has been found to be so by Kundt and Warburg and others within a wide range of pressure below one atm. It increases with the temperature.

Gas.	t° C	k_t	Ref.	Gas.	t° C	k_t	Ref.	Gas.	t° C	k_t	Ref.
Air*	−191	0.0000180	1	CO_2	100	0.0000496	1	Hg	203	0.0000185	3
"	0	0.0000566	1	C_2H_4	0	0.0000395	2	N_2	−191	0.0000183	1
"	100	0.0000719	1	He	−193	0.000146	1	"	0	0.0000568	1
Ar	−183	0.0000142	1	"	0	0.000344	4	"	100	0.0000718	1
"	0	0.0000388	1	"	100	0.000398	1	O_2	−191	0.0000172	1
"	100	0.0000509	1	H_2	−192	0.000133	1	"	0	0.0000570	1
CO	0	0.0000542	1	"	0	0.000416	4	"	100	0.0000743	1
CO_2	−78	0.0000219	1	"	100	0.000499	1	NO	8	0.000046	2
"	0	0.0000332	1	CH_4	0	0.0000720	4	N_2O	0	0.0000353	4

References: (1) Eucken, Phys. Z. 12, 1911; (2) Winkelmann, 1875; (3) Schwarze, 1903; (4) Weber, 1917.

* Air: $k_0 = 5.22\ (10^{-5})$ cal. cm^{-1} sec.$^{-1}$ deg. C^{-1}; 5.74 at 22°; temp. coef. = .0029; Hercus-Laby, Pr. R. Soc. A95, 190, 1919.

TABLE 259.—Diffusivities

The diffusivity of a substance = $h^2 = k/c\rho$, where k is the conductivity for heat, c the specific heat and ρ the density (Kelvin). The values are mostly for room temperatures, about 18° C.

Material.	Diffusivity.	Material.	Diffusivity.
Aluminum	0.826	Coal	0.002
Antimony	0.139	Concrete (cinder)	0.0032
Bismuth	0.0678	Concrete (stone)	0.0058
Brass (yellow)	0.339	Concrete (light slag)	0.006
Cadmium	0.467	Cork (ground)	0.0017
Copper	1.133	Ebonite	0.0010
Gold	1.182	Glass (ordinary)	0.0057
Iron (wrought, also mild steel)	0.173	Granite	0.0155
Iron (cast, also 1% carbon steel)	0.121	Ice	0.0112
Lead	0.237	Limestone	0.0092
Magnesium	0.883	Marble (white)	0.0090
Mercury	0.0327	Paraffin	0.00098
Nickel	0.152	Rock material (earth aver.)	0.0118
Palladium	0.240	Rock material (crustal rocks)	0.0064
Platinum	0.243	Sandstone	0.0133
Silver	1.737	Snow (fresh)	0.0033
Tin	0.407	Soil (clay or sand, slightly damp)	0.005
Zinc	0.402	Soil (very dry)	0.0031
Air	0.179	Water	0.0014
Asbestos (loose)	0.0035	Wood (pine, cross grain)	0.00068
Brick (average fire)	0.0074	Wood (pine with grain)	0.0023
Brick (average building)	0.0050		

Taken from An Introduction to the Mathematical Theory of Heat Conduction, Ingersoll and Zobel, 1913.

TABLE 260

THERMAL CONDUCTIVITY—LIQUIDS, PRESSURE EFFECT

(P. W. Bridgman, Proc. Amer. Acad., 59, 158, 1923.)

No.	Liquid	°C	Conductivity at 0 kg/cm²	Conductivity relative to unity 0 kg/cm² as function of pressure in kg/cm²							
				1000	2000	4000	6000	8000	10000	11000	12000
1	Methyl alcohol	30	.000505	1.201	1.342	1.557	1.724	1.864	1.986	2.043	2.097
		75	.000493	1.212	1.365	1.601	1.785	1.939	2.072	2.133	2.191
2	Ethyl alcohol	30	.000430	1.221	1.363	1.574	1.744	1.888	2.014	2.070	2.122
		75	.000416	1.233	1.400	1.650	1.845	2.007	2.152	2.217	2.278
3	Isopropyl alcohol	30	.000367	1.205	1.352	1.570	1.743	1.894	2.028	2.091	2.150
		75	.000363	1.230	1.399	1.638	1.812	1.962	2.093	2.154	2.211
4	Normal butyl alcohol	30	.000400	1.181	1.307	1.495	1.648	1.780	1.900	1.955	2.008
		75	.000391	1.218	1.358	1.559	1.720	1.859	1.985	2.043	2.099
5	Isoamyl alcohol	30	.000354	1.184	1.320	1.524	1.686	1.828	1.955	2.013	2.069
		75	.000348	1.207	1.348	1.557	1.724	1.868	1.998	2.063	2.126
6	Ether	30	.000329	1.305	1.509	1.800	2.009	2.177	2.322	2.388	2.451
		75	.000322	1.313	1.518	1.814	2.043	2.231	2.394	2.469	2.537
7	Acetone	30	.000429	1.184	1.315	1.511	1.659	1.786	1.900	Freezes	
		75	.000403	1.181	1.325	1.554	1.738	1.891	2.024	2.083	2.137
8	Carbon bisulphide	30	.000382	1.174	1.310	1.512	1.663	1.783	1.880	1.923	1.962
		75	.000362	1.208	1.366	1.607	1.789	1.935	2.054	2.107	2.154
9	Ethyl bromide	30	.000286	1.193	1.327	1.517	1.657	1.768	1.858	1.895	1.928
		75	.000273	1.230	1.390	1.609	1.772	1.907	2.022	2.073	2.121
10	Ethyl iodide	30	.000265	1.125	1.232	1.394	1.509	1.592	1.662	1.694	1.724
		75	.000261	1.148	1.265	1.442	1.570	1.671	1.757	1.799	1.837
11	Water	30	.00144	1.058	1.113	1.210	1.293	1.366	1.428	1.456	Freezes
		75	.00154	1.065	1.123	1.225	1.308	1.379	1.445	1.476	1.506
12	Toluol	30	.000364	1.159	1.286	1.470	1.604	1.716		(2.394*)	
		75	.000339	1.210	1.355	1.573	1.738	1.872	1.987	2.039	2.089
13	Normal pentane	30	.000322	1.281	1.483	1.777	1.987	2.163	2.325	2.404	2.481
		75	.000307	1.319	1.534	1.855	2.112	2.335	2.543	2.642	2.740
14	Petroleum ether	30	.000312	1.266	1.460	1.752	1.970	2.143	2.279	2.333	2.379
		75	.000302	1.268	1.466	1.780	2.026	2.232	2.409	2.488	2.561
15	Kerosene	75	.000333	1.185	1.314	1.502	1.654	1.792	1.925	1.990	2.054

1, 2, 6, 8, 12, 13, extreme purity; 3, 4, 5, 7, 9, 10, 11, very pure; 14, 15, commercial.
* Toluol freezes at 9900 kg/cm² at 30°. The figure at 11000 is for the solid.

TABLE 261.—The Unit of Thermal Resistance—the Fourier

The *fourier* is defined as that thermal resistance which will transfer heat energy at the rate of one joule per sec. (one watt) for each degree (centigrade) temperature difference between the terminal surfaces (equivalent roughly to a prism of Ag or Cu 4 cm long by 1 cm^2 cross section). (Harper, Journ. Wash. Acad. Sci., 18, 469, 1928.)

TABLE 262.—Factors to Reduce Heat Flow in Fouriers for a cm^3 to Other Units

To	watts/cm^2	cal./sec./cm^2	kilocal./hr./m^2	hp./$ft.^2$	hp./$ft.^2$	hp./$ft.^2$	watts/$in.^2$
Gradient	°C/cm	°C/cm	°C/m	°C/in.	°F./ft.	°F./in.	°C/in.
Multiples	1	4.18	.0116	4.14	44	3.67	.394

TABLE 263.—Conversion Factors Between Units of Current Density of Heat Flow. Quantity of Heat Energy Transferred Through Unit Area per Unit Time

	Joules/ sec. cm^2 watts/cm^2	Cal./sec. cm^2	Kilocal./hr./m^2	Hp./$ft.^2$	Watt/$in.^2$
1 watt/cm^2 =	1	.2391	8606	1.246	6.452
1 cal./sec./cm^2 =	4.183	1	36000	5.211	26.99
1 kilocal./hr./m^2 =	.0001162	.0000278	1	.0001448	.0007497
1 hp./$ft.^2$ =	.8027	.1919	6908	1	5.178
1 watt/$in.^2$ =	.1550	.03705	1334	.1931	1

The calorie is taken as 4.183 absolute joules.

TABLE 264.—Thermal Resistivities at 20°C Expressed in Fouriers for a Centimeter Cube

Silver	0.239
Copper	.258
Aluminum	.49
Brass (30% Zn)	.93
Iron	1.6
Nickel	1.7
Steel (1% C)	2.1
Constantan	4.4
Mercury	12.0
[Ice at 0°C]	45
Glass*	133
Concrete*	140
Water	170
Mica* (⊥ to laminations)	200
Firebrick*	200
[Firebrick 25°C to 1000°C]	90
Brick masonry*	250
Leather*	600
Hydrogen	600
Hard rubber	610
Helium	690
Rubber* (over 90%)	700
Wood (Virginia pine across grain)	710
Paper*	1000
Asbestos* (wool)	1100
Cork*	2000
Cotton batting (loose)	2500
Wool (loose)	2500
Air	4100
Carbon dioxide	6700

* Substances marked with the asterisk vary widely in thermal conductivity according to composition. For limits of such variation, consult International Critical Tables, Vol. 2. The figure listed above for any such material represents the author's estimate of the "best guess" for use in those cases where the composition of the material is not specified.

In preparing this table, the author has consulted Vol. 2, I.C.T. and has courteously been furnished advance values for some other materials by the editors of I.C.T. For still other materials, grateful acknowledgment is made to the staff of the Bureau of Standards, for advice in selecting most probable values in the light of present information.

TABLE 265.—Anti-Freezing Solutions (for automobile radiators, etc.)

(From Bur. Standards Letter Circulars No. 29, 1925.)
Per cent by vol. in water with freezing points and specific gravities.

Per cent by vol.	10%	20%	30%	40%	50%
Denatured alcohol	−3°C	−7°C	−12°C	−19°C	−28°C
(90% by vol.)*	.988	.978	.968	.957	.943
Wood alcohol†	−5°C	−12°C	−19°C	−29°C	−40°C
(97% by vol.)	.987	.975	.963	.952	.937
Distilled glycerine§	−2°C	−6°C	−11°C	−18°C	−26°C
(95% by vol.)	1.029	1.057	1.085	1.112	1.140
Ethylene glycol§	−3°C	−9°C	−16°C	−24°C	−35°C
(95% by vol.)	1.016	1.031	1.045	1.058	1.070

* 90% by vol. indicates quality of alcohol (180° proof); if 188 proof (that is containing only 6% water) amount required will be about 4% less.
† The vapor from wood alcohol is harmful. §Glycerine and ethylene glycol are practically nonvolatile and noncorrosive.

TABLE 266

LINEAR EXPANSION OF THE ELEMENTS

C is the true expansion coefficient at given temperature; R indicates reference to notes and authority, see page 282; M is the mean coefficient between given temperatures; where one temperature is given the true coefficient at that temperature is indicated; α and β are coefficients in formula $l_t = l_0\,(1 + \alpha t + \beta t^2)$; l_0 is length at 0° centigrade (unless otherwise indicated, when if x is standard temp., $l_t = l_x\,(1 + \alpha(t - t_x) + \beta(t - t_x)^2)$; l_t is length at t°C.

Element	Temp.	$C \times 10^4$	R	Temp. range	$M \times 10^4$	R	Temp. range	$\alpha \times 10^4$	$\beta \times 10^6$	R
Aluminum	20°	.224	1	100°	.235	1	0°, 500°	.22	.009	2
"	300	.284	1	500	.311	1				
Antimony	20	.136	3a	20	.080	3b				
Arsenic	20	.05	2							
Bismuth	20	.014	3a	20	.103	3b				
Cadmium	0	.54	4a	−180, −140	.59	4a	20, 140	.526		4a*
"	0	.20	4b	−180, −140	.117	4b	20, 140	.214		4b*
Carbon, diamond	50	.012	5							
Carbon, graphite	50	.06	2							
Chromium				20, 100	.068	30	20, 500	.086		30
Cobalt	20	.123	7				6, 121	.121	.0064	7
Copper	20	.162	8	100	.166	9	0, 625	.161	.0040	8
"	200	.170	9	300	.175	9				
Gold	20	.140	2	17, 100	.143	10	0, 520	.142	.0022	11
"				−191, 17	.132	10				
Indium	40	.417	5							
Iodine				−190, 17	.837	12				
Iridium	20	.065	13				0, 80	.0636	.0032	13
"							1070, 1720	.0679	.0011	14
Iron, soft	40	.1210	5	0, 100	.11	15				
" cast	20	.118					0, 750	.1158	.0053	8
" wrought	20	.119					0, 750	.1170	.0053	16
" steel	20	.114					0, 750	.1118	.0053	8
Lead (99.9)	20	.312	17	20, 100	.286	17	100, 240	.269	.011	9
	100	.291	17	20, 200	.295	17				
	280	.343	9							
Magnesium	20	.254	19	−100, + 20	.240	18	+ 20, 500	.2480	.0096	18
				20, 100	.260	18				
Manganese	20	.233	2	0, 100	.228	6				
				−190, 0	.159	6	20, 300	.216	.0121	6
Molybdenum†	20	.053	2	0, 100	.052	6	−142, 19	.0515	.0057	20
				25, 100	.049	20	19, +305	.0501	.0014	20
				25, 500	.055	20				
Nickel	20	.126	2	0, 100	.130	6	−190, + 20	.1308	.0166	6
							+ 20, +300	.1236	.0066	6
							500, 1000	.1346	.0033	16
Osmium	40	.066	5							
Palladium	20	.1173	2				−190, +100	.1152	.00517	21
							0, 1000	.1167	.0022	16
Platinum	20	.0887	19	−190, −100			−190, −100	.0875	.00314	19
	20	.0893	2				0, + 80	.0890	.00121	13
							0, 1000	.0887	.00132	16
Potassium				0, 50	.83	22				
Rhodium	40	.0850	5	6, 21	.0876	23	− 75, −112	.0746		23*
Ruthenium	40	.0963	5							
Selenium	0	.439	24	0, 100	.660	25				
Silicon	40	.0763	5	− 3, + 18	.0249	23	− 75, − 67	.0182		23*
Silver	20	.1846	16	0, 100	.197	19	0, 875	.1827	.00479	16
	20	.195	19				20, 500	.1939	.00295	19
Sodium				−190, − 17	.622	12	0, 50	.72		22*
Steel, 36.4 Ni				20, 260	.031	17	260, 500	.144		17*
				20, 340	.055	17	340, 500	.136		17*
Tantalum†	20	.065	6	− 78, 0	.059	6	20, 400	.0646	.0009	6
				0, 100	.0655	6				
Tellurium	20	.016	3a	20	.272	3b				
Thallium	40	.302	5							
Tin	20	.214	26				8, 95	.2033	.0263	26
	20	.305	3a	20	.154	3b				
Tungsten†	27	.0444	27	0, 100	.045	6	−105, +502	.0428	.00058	28
Zinc	20	.305	3a	−140, −100	.656	4a	0, 400	.354	.010	29a
	20	.154	3b	+ 20, 100	.639	4a				
	20	.358	29	+ 20, 100	.141	4b				

* For references, see page 282.

† Molybdenum, t 300° to 2500° $l_t = l_{300}\,[1 + 5.00 \times 10^{-6}\,(t - 300) + 10.5 \times 10^{-10}\,(t - 300)^2]$ Worthing, 1926
Tantalum, 300° to 2800° $l_t = l_{300}\,[1 + 6.60 \times 10^{-6}\,(t - 300) + 5.2 \times 10^{-10}\,(t - 300)^2]$ Worthing, 1926
Tungsten, 300° to 2700° $\log_t = l_{300}\,[1 + 4.44 \times 10^{-6}\,(t - 300) + 4.5 \times 10^{-10}\,(t - 300)^2]$ Worthing, 1926

TABLE 267

LINEAR EXPANSION OF MISCELLANEOUS SUBSTANCES

The coefficient of cubical expansion may be taken as three times the linear coefficient. t is the temperature or range of temperature, C the coefficient of expansion, and A. the authority. For reference see page 282.

Substance.	t	$C \times 10^4$	A.
Brass:			
Cast	0–100	0.1875	1
Wire	"	0.1930	1
"	"	.1783–.193	2
71.5 Cu + 27.7 Zn + 0.3 Sn + 0.5 Pb	40	0.1859	3
71 Cu + 29 Zn	0–100	0.1906	4
Bronze:			
3 Cu + 1 Sn	16.6–100	0.1844	5
" " " " "	16.6–350	0.2116	5
" " " " "	16.6–957	0.1737	5
86.3 Cu + 9.7 Sn + 4 Zn	40	0.1782	3
97.6 Cu + 2.2 Sn + 0.2 P { hard	0–80	0.1713	6
{ soft	"	0.1708	6
Caoutchouc	—	0.657–0.686	2
"	16.7–25.3	0.770	7
Constantan	4–29	0.1523	—
Ebonite	25.3–35.4	0.842	7
Fluor spar: CaF_2	0–100	0.1950	8
German silver	"	0.1836	8
Gold-platinum:			
2 Au + 1 Pt	"	0.1523	4
Gold-copper:			
2 Au + 1 Cu	"	0.1552	4
Glass:			
Tube	"	0.0833	1
"	"	0.0828	9
Plate	"	0.0891	10
Crown (mean)	"	0.0897	10
" "	50–60	0.0954	11
Flint	"	0.0788	11
Jena thermometer 16^{III} normal	0–100	0.081	12
" 59^{III}	"	0.058	12
" "	−191 to +16	0.424	13
Gutta percha	20	1.983	14
Ice	−20 to −1	0.51	15
Iceland spar:			
Parallel to axis	0–80	0.2631	6
Perpendicular to axis	"	0.0544	6
Lead-tin (solder)			
2 Pb + 1 Sn	0–100	0.2508	1
Magnalium	12–39	0.238	16
Manganin	—	0.181	—
Marble	15–100	0.117	17
Paraffin	0–16	1.0662	18
"	16–38	1.3030	18
"	38–49	4.7707	18
Platinum-iridium			
10 Pt + 1 Ir	40	0.0884	3

Substance.	t	$C \times 10^4$	A.
Platinum-silver:			
1 Pt + 2Ag	0–100	0.1523	4
Porcelain	20–790	0.0413	19
" Bayeux	1000–1400	0.0553	20
Quartz:			
Parallel to axis	0–80	0.0797	6
" "	−190 to +16	0.0521	21
Perpend. to axis	0–80	0.1337	6
Quartz glass	−190 to +16	−0.0026	13
" "	16 to 500	0.0057	26
" "	16–1000	0.0058	26
Rock salt	40	0.4040	3
Rubber, hard	0°	0.691	27
" "	−160	0.300	27
Speculum metal	0–100	0.1933	1
Topaz:			
Parallel to lesser horizontal axis	"	0.0832	8
Parallel to greater horizontal axis	"	0.0836	8
Parallel to vertical axis	"	0.0472	8
Tourmaline:			
Parallel to longitudinal axis	"	0.0937	8
Parallel to horizontal axis	"	0.0773	8
Type metal	16.6–254	0.1952	5
Vulcanite	0–18	0.6360	22
Wedgwood ware	0–100	0.0890	5
Wood:			
Parallel to fiber:			
Ash	"	0.0951	23
Beech	2.34	0.0257	24
Chestnut	"	0.0649	24
Elm	"	0.0565	24
Mahogany	"	0.0361	24
Maple	"	0.0638	24
Oak	"	0.0492	24
Pine	"	0.0541	24
Walnut	"	0.0658	24
Across the fiber:			
Beech	"	0.614	24
Chestnut	"	0.325	24
Elm	"	0.443	24
Mahogany	"	0.404	24
Maple	"	0.484	24
Oak	"	0.544	24
Pine	"	0.341	24
Walnut	"	0.484	24
Wax: White	10–26	2.300	25
" "	26–31	3.120	25
" "	31–43	4.860	25
" "	43–57	15.227	25

Duralumin, .94 Al,	20-100°,	.000023	20-300°,	.000025	Hidnert, '22
Steel, .14 C, 34.5 Ni	25-100°,	.0000037	25-600°,	.0000136	"
Monel metal,	25-100°,	.000014	25-600°,	.000016	

Insulating materials, Souder-Hidnert, 1919:

Bakelite, bleached,	20-60°,	.000022	Marble,	25-100°,	$10 - 16 \times 10^{-6}$
Celluloid,	20-70°,	.000100	Porcelain,	20-200°,	$3 - 11 \times 10^{-6}$
Limestone,	25-100°,	.000009	Hard rubber,	20-60°,	.00008

TABLE 268

CUBICAL EXPANSION OF SOLIDS

If v_2 and v_1 are the volumes at t_2 and t_1 respectively, then $v_2 = v_1(1 + C\Delta t)$, C being the coefficient of cubical expansion and Δt the temperature interal. Where only a single temperature is stated C represents the true coefficient of cubical expansion at that temperature. The coefficient of cubical expansion may be taken as three times the linear coefficient.

Substance.	t or Δt	$C \times 10^4$	Authority.
Antimony	0–100	0.3167	Matthiessen
Beryl	0–100	0.0105	Pfaff
Bismuth	0–100	0.3948	Matthiessen
Copper	0–100	0.4998	"
Diamond	40	0.0354	Fizeau
Emerald	40	0.0168	"
Galena	0–100	0.558	Pfaff
Glass, common tube	0–100	0.276	Regnault
" hard	0–100	0.214	"
" Jena, borosilicate 59 III	20–100	0.156	Scheel
" pure silica	0–80	0.0129	Chappuis
Gold	0–100	0.4411	Matthiessen
Ice	—20—1	1.1250	Brunner
Iron	0–100	0.3550	Dulong and Petit
Lead	0–100	0.8399	Matthiessen
Paraffin	20	5.88	Russner
Platinum	0–100	0.265	Dulong and Petit
Porcelain, Berlin	20	0.0814	Chappuis and Harker
Potassium chloride	0–100	1.094	Playfair and Joule
" nitrate	0–100	1.967	" " "
" sulphate	20	1.0754	Tutton
Quartz	0–100	0.3840	Pfaff
Rock salt	50–60	1.2120	Pulfrich
Rubber	20	4.87	Russner
Silver	0–100	0.5831	Matthiessen
Sodium	20	2.1364	E. Hazen
Stearic acid	33.8–45.5	8.1	Kopp
Sulphur, native	13.2–50.3	2.23	"
Tin	0–100	0.6889	Matthiessen
Zinc	0–100	0.8928	"

References to Table 266, page 280: (1) Uffelmann, 1930. (2) Mean. (3a) Bridgman, 1924-5, parallel to axis. (3b) ditto, perpendicular to axis. (4a) Grüneisen, paral. axis, hexag. (4b) ditto, perpendicular. (5) Fizeau. (6) Disch, 1921. (7) Tutton, 1899. (8) Dittenberger, 1902. (9) Uffelmann, 1930. (10) Grüneisen, 1910. (11) Müller, 1916. (12) Dewar, 1902. (13) Benoit, 1889. (14) Holborn, 1897. (15) Le Chatelier, 1899. (16) Holborn, Day, 1900. (17) Hidnert, Sweeney, 1930. (18) ditto, 1928. (19) Scheel, 1921. (20) Hidnert, Shad, 1919. (21) Scheel, 1907. (22) Hagen, 1883. (23) Valentiner, Wallot, 1915. (24) Dorsey, 1908. (25) Spring, 1881. (26) Matthiessen. (27) Worthing, 1917. (28) Hidnert, Sweeney, 1925. (29) Schulze, 1921. (30) Hidnert, 1931.

References to Table 267, page 281: (1) Smeaton. (2) Various. (3) Fizeau. (4) Matthiessen. (5) Daniell. (6) Benoit. (7) Kohlrausch. (8) Pfaff. (9) Deluc. (10) Lavoisier and Laplace. (11) Pulfrich. (12) Schott. (13) Henning. (14) Russner. (15) Mean. (16) Stadthagen. (17) Fröhlich. (18) Rodwell. (19) Braun. (20) Deville and Troost. (21) Scheel. (22) Mayer. (23) Glatzel. (24) Villari. (25) Kopp. (26) Randall. (27) Dorsey.

Note: Crucibles of thorium oxide may be used for $t < 3000°$ C; magnesium oxide, $< 1800°$ C; beryllium oxide, $< 2000°$ C. Swanger, Caldwell, Bur. Standards, Journ. Res., 6, 1131, 1931, which see for further information about use of crucibles.

TABLE 269

CUBICAL EXPANSION OF LIQUIDS

If V_o is the volume at 0° then at t° the expansion formula is $V_t = V_o(1 + \alpha t + \beta t^2 + \gamma t^3)$. The table gives values of α, β and γ and of C, the true coefficient of cubical expansion, at 20° for some liquids and solutions. Δt is the temperature range of the observation and A. the authority.

Liquid.	Δt	$\alpha\ 10^3$	$\beta\ 10^6$	$\gamma\ 10^8$	$C\ 10^3$ at 20°	A.
Acetic acid	16–107	1.0630	0.12636	1.0876	1.071	3
Acetone	0–54	1.3240	3.8090	—0.87983	1.487	3
Alcohol:						
Amyl	—15–80	0.9001	0.6573	1.18458	0.902	4a
Ethyl, 30% by vol.	18–39	0.2928	10.790	—11.87	–	6
" 50% "	0–39	0.7450	1.85	0.730	–	6
" 99.3% "	27–46	1.012	2.20	–	1.12	6
" 500 atmo. press.	0–40	0.866	–	–	–	1
" 3000 " "	0–40	0.524	–	–	–	1
Methyl	0–61	1.1342	1.3635	0.8741	1.199	5a
Benzene	11–81	1.17626	1.27776	0.80648	1.237	5a
Bromine	0–59	1.06218	1.87714	—0.30854	1.132	2
Calcium chloride:						
5.8% solution	18–25	0.07878	4.2742	–	0.250	7
40.9% "	17–24	0.42383	0.8571	–	0.458	7
Carbon disulphide	—34–60	1.13980	1.37065	1.91225	1.218	4a
500 atmos. pressure	0–50	0.940	–	–	–	1
3000 " "	0–50	0.581	–	–	–	1
Carbon tetrachloride	0–76	1.18384	0.89881	1.35135	1.236	4b
Chloroform	0–63	1.10715	4.66473	—1.74328	1.273	4b
Ether	—15–38	1.51324	2.35918	4.00512	1.656	4a
Glycerine	–	0.4853	0.4895	–	0.505	8
Hydrochloric acid:						
33.2% solution	0–33	0.4460	0.215	–	0.455	9
Mercury	0–100	0.18182	0.0078	–	0.18186	13
Olive oil	–	0.6821	1.1405	—0.539	0.721	10
Pentane	0–33	1.4646	3.09319	1.6084	1.608	14
Potassium chloride:						
24.3% solution	16–25	0.2695	2.080	–	0.353	7
Phenol	36–157	0.8340	0.10732	0.4446	1.090	11
Petroleum:						
Density 0.8467	24–120	0.8994	1.396	–	0.955	12
Sodium chloride:						
20.6% solution	0–29	0.3640	1.237	–	0.414	9
Sodium sulphate:						
24% solution	11–40	0.3599	1.258	–	0.410	9
Sulphuric acid:						
10.9% solution	0–30	0.2835	2.580	–	0.387	9
100.0%	0–30	0.5758	—0.432	–	0.558	9
Turpentine	—9–106	0.9003	1.9595	—0.44998	0.973	5b
Water	0–33	—0.06427	8.5053	—6.7900	0.207	13

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TABLE 270

THERMAL EXPANSION OF GASES

Pressures are given in centimeters of mercury.

Coefficient at Constant Volume.

Substance.	Pressure cm.	Coefficient × 100.	Reference.
Air	.6	.37666	1
"	1.3	.37172	"
"	10.0	.36630	"
"	25.4	.36580	"
"	75.2	.36660	"
" 0°–100°	100.1	.36744	2
"	76.0	.36650	3
"	200.0	.36903	"
"	2000.	.38866	"
"	10000.	.4100	"
Argon	51.7	.3668	4
Carbon dioxide	76.0	.36856	3
" "	1.8	.36753	1
" "	5.6	.36641	"
" "	74.9	.37264	"
" " 0°–20°	51.8	.36985	2
" " 0°–40°	51.8	.36972	"
" " 0°–100°	51.8	.36981	"
" " 0°–20°	99.8	.37335	"
" " 0°–100°	99.8	.37262	"
" " 0°–100°	100.0	.37248	5
Carbon monoxide	76.	.36667	3
Helium	56.7	.3665	4
Hydrogen 16°–132°	.0077	.3328	6
" 15°–132°	.025	.3623	"
" 12°–185°	.47	.3656	"
"	.93	.37002	1
"	11.2	.36548	"
"	76.4	.36504	"
" 0°–100°	100.0	.36626	2
Nitrogen 13°–132°	.06	.3021	6
" 9°–133°	.53	.3290	"
" 0°–20°	100.2	.36754	2
" 0°–100°	100.2	.36744	"
"	76.	.36682	7
Oxygen 11°–132°	.007	.4161	6
" 9°–132°	.25	.3984	"
" 11°–132°	.51	.3831	"
"	1.9	.36683	8
"	18.5	.36690	"
"	75.9	.36681	"
Nitrous oxide	76.	.3676	3
Sulph'r dioxide SO_2	76.	.3845	"

Coefficient at Constant Pressure.

Substance.	Pressure cm.	Coefficient × 100.	Reference.
Air	76.	.3671	3
"	257.	.3693	"
" 0°–100°	100.1	.36728	2
Hydrogen 0°–100°	100.0	.36600	"
"	200 Atm.	.332	9
"	400 "	.295	"
"	600 "	.261	"
"	800 "	.242	"
Carbon dioxide	76.	.3710	3
" " 0°–20°	51.8	.37128	2
" " 0°–40°	51.8	.37100	"
" " 0°–100°	51.8	.37073	"
" " 0°–20°	99.8	.37602	"
" " 0°–100°	99.8	.37410	"
" " 0°–20°	137.7	.37972	"
" " 0°–100°	137.7	.37703	"
" " 0°–7.5°	2621.	.1097	6
" " 64°–100°	2621.	.6574	"
Carbon monoxide	76.	.3669	3
Nitrous oxide	76.	.3719	"
Sulphur dioxide	76.	.3903	"
" "	98.	.3980	"
Water-vapor 0°–119°	76.	.4187	10
Water-vapor 0°–141°	76.	.4189	"
Water-vapor 0°–162°	76.	.4071	"
Water-vapor 0°–200°	76.	.3938	"
Water-vapor 0°–247°	76.	.3799	"

Thomson has given, Encyc. Brit. "Heat," the following for the calculation of the expansion, E. between 0° and 100° C. Expansion is to be taken as the change of volume under constant pressure:

Hydrogen, $E = .3662(1 - .00049V/v)$,
Air, $E = .3662(1 - .0026\ V/v)$,
Oxygen, $E = .3662(1 - .0032\ V/v)$,
Nitrogen, $E = .3662(1 - .0031\ V/v)$,
CO_2 $E = .3662(1 - .0164\ V/v)$.

V/v is the ratio of the actual density of the gas at 0° C to what it would have at 0° C and 1 Atm. pressure.

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TABLE 271

SPECIFIC HEAT OF THE CHEMICAL ELEMENTS

When one temperature is given the true specific heat is given, otherwise the mean specific heat between the given limits. See page 289 for references.

Element	t°C	Sp.ht.	Ref.	Element	t°C	Sp.ht.	Ref.
Aluminum	−250	0.0039	..	Carbon, graph	−183	0.0025	19
	−200	.076	..		−66	.053	19
	−150	.1367	1		11	.112	19
	−100	.1676	1		85	.177	19
	−50	.1914	1		896	.454	19
	0	.2079	1	C, diamond	0	.1044	20
	100	.225	..		223	.264	20
	300	.248	2		823	.428	20
	600	.277	2	Cerium	−253, −196	.033	21
	16, 100	.212	3		20, 100	.0511	22
Antimony*	−207.1	.0322	4	Chlorine	0, 24	.226	23
	−150	.0412	1	Chromium	−150	.0599	1
	−100	.0448	1		−100	.0797	1
	−50	.0476	1		−50	.0941	1
	0	.0494	1		0	.1044	1
	28	.0477	5		100	.112	25
	20, 100	.0504	6		500	.150	7
	500	.054	*		600	.187	25
Arsenic	−216	.032	4		18, 100	.111	24
	−117.6	.0666	4	Cobalt	−150	.0672	1
	18	.078	4		−100	.0809	1
Barium	−185, +20	.068	7		−50	.0914	1
Beryllium	−202	.017	8		0	.1028	1
	45, 50	.445	9		20	.1001	*
	0, 100	.425	10		100	.1067	*
Bismuth*	−150	.0264	1		200	.1134	*
	−100	.0273	1	Copper	−189	.0506	26
	−50	.0282	1		−150	.0674	1
	0	.0291	1		−100	.0783	1
	20	.0294	*		−50	.0862	1
	100	.0304	*		0	.0910	1
fluid	297	.0292	4		100	.0939	*
Boron	100	.287	11		900	.1259	27
	500	.472	11		18, 100	.0928	24
	900	.510	11		18, 600	.0994	24
	−76, 0	.168	12	Gallium	−258.1	.0049	29
	0, 100	.307	13		−213.1	.044	29
Bromine, (s)	−253.1	.0205	14		−73.1	.084	29
(s)	−173.1	.0659	14	Germanium	0, 100	.074	10
(s)	−73.1	.080	14	Gold	−258.1	.0018	29
(s)	−13.1	.088	14		−252.8	.0040	29
(l)	13, 45	.107	15		−209.5	.0211	29
Cadmium	−263	.0019	16		−150	.0266	1
	−203.1	.0415	16		−100	.0281	1
	−103.1	.0518	16		−50	.0293	1
	27.9	.0552	16		0	.0302	1
	107.9	.0569	16		18	.0312	30
	277	.060	16		100	.0314	30
Caesium	0, 26	.0482	17	Indium	0, 100	.057	31
Calcium	24	.168	18	Iodine	−263.2	.0037	32
	100	.1625	2		−255.9	.0118	32
	300	.1832	2		−221.1	.0353	32
	600	.188	2		−90, +17	.0485	33
Carbon, graph.	−191, −79	.057	12	Iridium	−186, +18	.0282	34
	−76, 0	.126	12		18, 100	.0323	34

SPECIFIC HEAT OF THE CHEMICAL ELEMENTS

Element	t°C	Sp.ht.	Ref.	Element	t°C	Sp.ht.	Ref.
Iron, pure	−256.2	0.00067	26	Molybdenum	− 34.5	0.0561	44
	−240.7	.00355	26		0	.0589	45
	−214.0	.0194	26		+ 5.3	.0589	44
	−172.6	.0512	26		+100	.0612	45
	− 67.5	.0939	26		250	.0632	45
	0	.1043	..	Nickel	−258	.0008	26
α, β, γ	100	.115	27		−247.9	.0024	26
	500	.163	27		−201.2	.0363	42
	760	.320	27		−150	.0660	1
	1000	.162	27		−100	.0817	1
γ	100	.127	26		− 50	.0940	1
	700	.157	26		0	.1032	1
	1000	.162	26		100	.1146	35
Lanthanum	0, 100	.0448	36		500	.1270	35
Lead	−270	.00001	37		800	.1413	35
	−267	.00086	38	Osmium	19, 98	.0311	46
	−259	.0073	38	Palladium	−180,+18	.0528	34
	−150	.0279	1		0	.0538	47
	−100	.0283	1		100	.0564	47
	− 50	.0289	1		500	.0653	47
	0	.0297	1		900	.0717	47
	100	.0320	35		1500	.0766	47
	300	.0356	35	Phosphorus, yellow	−136	.124	5
(l)	360	.0375	35		− 40	.165	5
	500	.0370	35		+ 9	.189	5
Lithium	−183	.3	39	(red)	−136	.107	5
	−100	.600	40		− 40	.182	5
	50	.96	39		+ 9	.190	5
	+190	1.374	40	Platinum	−255.6	.00123	44
Magnesium	−150	.1767	1		−237.7	.0073	44
	−100	.2025	1		−191.7	.0211	44
	− 50	.2228	1		−152.1	.0261	44
	0	.2316	1		− 64.8	.0307	44
	100	.257	2		0	.03162	1
	300	.279	2		500	.0349	47
	600	.311	2		750	.0365	47
(l)	650, 775	.284	41		1000	.0381	47
Manganese	−188, −79	.0820	33		1300	.0400	47
	−79, +15	.1091	33		20, 100	.0319	47
	60	.1211	33		20, 1000	.0346	47
	325	.1783	33	Potassium	−258.4	.032	44
	20, 100	.1211	33		−255.8	.045	44
	−100	.0979	40		−201.3	.140	44
	0	.1072	40		− 53.1	.172	44
	100	.1143	40		+ 3.4	.177	44
Mercury (s)	−263.3	.00552	42	(l)	90	.200	48
	−267.2	.00620	42		181	.196	48
	−259.8	.00783	42	Rhenium	0, 20	.035	49
	−245.6	.0172	42	Rhodium	10, 97	.058	46
	−220.2	.0255	42	Rubidium (s)	0	.0802	50
	−163.7	.0298	42	(l)	50	.0908	50
	− 81.4	.0324	42	Ruthenium	0, 100	.0611	31
	− 43.1	.0337	43	Selenium	3	.072	51
(l)	− 33.1	.0338	43		16.5	.075	52
(See Table 276)	− 3.1	.0335	43		20.5	.077	52
	+ 17	.0333	43		29.5	.085	52
Molybdenum	−257	.0004	44		32	.127	52
	−239.1	.0034	44		38	.131	52
	−181.5	.0300	44		41.7	.130	52
	−152.7	.0399	44		20	.09	..

TABLE 271 (*concluded*).—Specific Heat of the Chemical Elements

Element	t°C	Sp.ht.	Ref.
Silicon	−212	0.029	53
	−143.3	.087	53
	− 86.2	.126	53
	+ 13.9	.168	53
	18.2, 99.1	.181	54
	18.0, 900.6	.210	54
Silver	−238	.0146	28
	−150	.0461	1
	−100	.0505	1
	− 50	.0537	1
	0	.0557	1
	100	.0564	*
	300	.0601	2
	900	.0685	2
	20–900	.0650	55
	20–1200	.0880	55
Sodium	−256.1	.026	44
	−238.5	.108	44
	−155.5	.245	44
(l)	100	.32	..
Sulphur	−188, +18	.137	57
(l)	115, 160	.220	56
rhom	15, 96	.176	56
monochin	0, 52	.181	58
Tantalum	−201.7	.0205	8
	+380	.035	59
	900	.036	59
	1100	.043	59
	1400	.044	59
Tellurium	−188, +18	.047	57
	15, 100	.0483	60
	15, 200	.0487	60
Thallium	−135	.288	..
	28	.311	5
	20, 100	.0326	61
Thorium	−253, −196	0.0197	21
	0, 100	.0276	62
Tin	−203.5	.0385	63
	−186.7	.0422	63
	−150	.0450	1
	−100	.0483	1
	− 50	.0512	1
	0	.0536	1
	+ 25	.0548	63
	100	.0577	*
	1100	.0758	64
Titanium	−185, +20	.082	7
	0, 100	.1125	10
Tungsten	−247.1	.0012	32
	−218.4	.0098	32
	−173.1	.0205	65
	− 73.1	.0288	65
	+ 26.9	.0321	65
	100	.0320	66
	500	.0344	66
	1000	.0367	66
	1500	.0390	66
Uranium	0, 98	.0280	67
Vanadium	0, 100	.1153	68
Zinc	0, 100	.095	..
	−252.4	.0071	69
	−201.3	.0573	69
	−150	.0740	1
	−100	.0814	1
	− 50	.0871	1
	0	.0913	1
	100	.0957	*
	300	.1043	2
	400	.1089	2

TABLE 272.—Formulae for True Specific Heats

Element	Formula	Range °C
Antimony	$0.0493 + 0.000012\,t$	0–500
Bismuth	$.0292 + .000012\,t$	0–200
Chromium	$.1055 + .00010\,t - 0.00000015\,t^2$	0–400
Cobalt	$.1000 + .000067\,t$	0–400
Copper	$.0915 + .000024\,t$	0–300
Iron	$.1060 + .000096\,t$	0–400
Lead	$.0295 + .00002\,t$	0–300
Magnesium	$.2370 + .000142\,t - .0000001\,t^2$	0–400
Nickel	$.1020 + .000118\,t - .00000006\,t^2$	0–300
Platinum	$.03162 + .00000617\,t + 2.33 \times 10^{10} t^2$	0–1625
Silver	$.0556 + .000008\,t$	0–400
Tin	$.0525 + .000052\,t$	0–200
Zinc	$.0913 + .000044\,t$	0–300

Pt from Jaeger & Rosenbaum, 1928. Others recalculated by Dr. W. P. White (1931), mainly from Schübel.

HEAT CAPACITIES, TRUE AND MEAN SPECIFIC HEATS, AND LATENT HEATS AT FUSION (SEE PP. 285-287)

The following data are taken from a research and discussion entitled "Die Temperatur-Wärmeinhaltskurven der technisch wichtigen Metalle," Wüst, Meuthen und Durrer, Forschungsarbeiten herausgegeben vom Verein Deutscher Ingenieure, Springer, Heft 204, 1918.

(*a*) There follow the constants of the equation for the heat capacity: $W = a + bt + ct^2$; for the mean specific heat: $s = at^{-1} + b + ct$; and for the true specific heat: $s' = b + 2ct$; also the latent heats at fusion. Much greater faith should be given to tables on pages 285 to 287.

Element	Temperature range. °C	a	b	$c \times 10^6$	Latent heat. cal./g	Element	Temperature range. °C	a	b	$c \times 10^6$	Latent heat cal./g
Cr	0–1500	—	0.10233	33.47	—	Ag	0–961	—	0.05725	5.48	26.0
Mo	0–1500	—	0.06162	10.99	—		961–1300	53.17	0.00710	28.30	—
W	0–1500	—	0.03325	1.07	—	Au	0–1064	—	0.03171	1.30	15.9
Pt	0–1500	—	0.03121	3.54	—		1064–1300	26.35	0.01420	8.52	—
Sn	0–232	—	0.06829	—	13.8	Cu	0–1084	—	0.10079	3.05	41.0
	232–1000	14.33	0.07020	−18.30	—		1084–1300	130.74	−.04150	65.6	—
Bi	0–270	—	0.03141	5.22	10.2	Mn	0–1070	—	0.12037	25.41	36.6
	270–1000	10.31	0.03107	5.41	—		1130–1210	−7.41	0.17700	—	24.14*
Cd	0–321	—	0.05550	6.28	10.8		1230–1250	3.83	0.19800	—	—
	321–1000	6.30	0.06952	6.37	—	Ni	0–320	—	0.10950	52.40	56.1
Pb	0–327	—	0.03591	11.47	5.47		330–1451	0.41	0.12931	0.11	1.33*
	327–1000	6.07	0.02920	−3.30	—		1451–1520	50.21	0.13380	—	—
Zn	0–419	—	0.08777	43.48	23.0	Co	0–950	—	0.09119	40.77	58.2
	419–1000	14.34	0.13340	−16.10	—		1100–1478	22.00	0.11043	14.57	14.70*
Sb	0–630	—	0.05179	3.00	38.9		1478–1600	57.72	0.14720	—	—
	630–1000	39.42	0.05090	2.96	—	Fe	0–725	—	0.10545	56.84	49.4
Al	0–657	—	0.22200	38.57	94.0		785–919	−1.63	0.1592	—	6.56*
	657–1000	102.39	0.21870	24.00	—		919–1404	18.31	0.14472	0.05	6.67*
							1405–1528	−77.18	0.21416	—	1.94*
							1528–1600	70.03	0.15012	—	—

* Allotropic heat of transformation: Mn, 1070–1130°; Ni, 320–330°; Co, 950–1100°; Fe, 725–785°; 919° ± 1; 1404.5° ± 0.5.

(*b*) TRUE SPECIFIC HEATS

°C	Pb	Zn	Al	Ag	Au	Cu	Ni	Fe	Co	Silica glass
0	0.0359	0.0878	0.2220	0.0573	0.0317	0.1008	0.1095	0.1055	0.0912	—
100	0.0382	0.0965	0.2297	0.0583	0.0320	0.1014	0.1200	0.1168	0.0993	0.2372
200	0.0405	0.1052	0.2374	0.0594	0.0322	0.1020	0.1305	0.1282	0.1073	0.2416
300	0.0428	0.1139	0.2451	0.0605	0.0325	0.1026	0.1409	0.1396	0.1154	0.2460
400	—	0.1226	0.2529	0.0616	0.0328	0.1032	0.1294	0.1509	0.1235	0.2504
500	—	0.1173	0.2606	0.0627	0.0330	0.1038	0.1294	0.1623	0.1316	0.2548
600	—	0.1141	0.2683	0.0638	0.0333	0.1045	0.1294	0.1737	0.1396	0.2592
700	—	0.1109	0.2523	0.0649	0.0335	0.1051	0.1295	0.1850	0.1477	0.2636
800	—	0.1076	0.2571	0.0660	0.0338	0.1057	0.1295	0.1592	0.1558	0.2680
900	—	0.1044	0.2619	0.0671	0.0341	0.1063	0.1295	0.1592	0.1639	0.2724
1000	—	0.1012	0.2667	0.0637	0.0343	0.1069	0.1295	0.1448	—	0.2768
1100	—	—	—	0.0694	0.0329	0.1028	0.1296	0.1448	0.1424	0.2812
1200	—	—	—	0.0750	0.0346	0.1159	0.1296	0.1448	0.1454	0.2856
1300	—	—	—	0.0807	0.0364	0.1291	0.1296	0.1449	0.1483	0.2900
1400	—	—	—	—	—	—	0.1296	0.1449	0.1512	0.2944
1500	—	—	—	—	—	—	0.1338	0.2142	0.1472	0.2988
1600	—	—	—	—	—	—	—	0.1501	0.1472	—

For more elaborate tables and for all the elements in upper table, see original reference.

ATOMIC HEATS (50°K.), SPECIFIC HEATS (50°K.), ATOMIC VOLUMES OF THE ELEMENTS

The atomic and specific heats are due to Dewar, Pr. Roy. Soc. 89A, 168, 1913

Element.	Specific heat −223° C.	Atomic heat −223°C.	Atomic volume.	Element.	Specific heat −223° C.	Atomic heat −223°C.	Atomic volume.	Element.	Specific heat −223° C.	Atomic heat −223°C.	Atomic volume.
Li	0.1924	1.35	13.0	Cr	0.0142	0.70	7.6	Sn	0.0286	3.41	20.3
Gl	0.0137	0.125	4.9	Mn	0.0229	1.26	7.4	Sb	0.0240	2.89	18.2
B	0.0212	0.24	4.5	Fe	0.0175	0.98	7.1	I	0.0361	4.59	25.7
C *	0.0137	0.16	5.1	Ni	0.0208	1.22	6.7	Te	0.0288	3.68	21.2
C †	0.0028	0.03	3.4	Co	0.0207	1.22	6.8	Cs	0.0513	6.82	71.0
Na	0.1519	3.50	23.6	Cu	0.0245	1.56	7.1	Ba¶	0.0350	4.80	36.6
Mg	0.0713	1.74	14.1	Zn	0.0384	2.52	9.2	La	0.0322	4.60	22.6
Al	0.0413	1.12	10.0	As	0.0258	1.94	15.9	Ce	0.0330	4.64	20.3
Si ‡	0.0303	0.86	14.2	Se	0.0361	2.86	18.5	W	0.0095	1.75	9.8
Si §	0.0303	0.77	11.4	Br	0.0453	3.62	24.9	Os	0.0078	1.49	8.5
P				Rb	0.0711	6.05	55.8	Ir	0.0099	1.92	8.6
yel.	0.0774	2.40	17.0	Sr¶	0.0550	4.82	34.5	Pt	0.0135	2.63	9.2
P				Zr	0.0262	2.38	21.8	Au	0.0160	3.16	10.2
red	0.0431	1.34	13.5	Mo	0.0141	1.36	9.3	Hg	0.0232	4.65	14.8
S	0.0546	1.75	16.	Ru	0.0109	1.11	9.0	Tl	0.0235	4.80	17.2
Cl	0.0967	3.43	24.6	Rh	0.0134	1.38	8.5	Pb	0.0240	4.96	18.3
K	0.1280	5.01	44.7	Pd	0.0190	2.03	9.2	Bi	0.0218	4.54	21.3
Ca	0.0714	2.86	25.9	Ag	0.0242	2.62	10.2	Th	0.0197	4.58	21.1
Ti	0.0205	0.99	10.7	Cd	0.0308	3.46	13.0	U	0.0138	3.30	12.8

* Graphite. † Diamond. ‡ Fused. § Crystallized. ¶ Impure.

References to Table 271: * Values derived from formulae recalculated by Dr. W. P. White from Schübel's results. The Pt formula is from Jaeger and Rosenbaum. (1) Schimpff values interpolated by White. (2) Eastman, William Young, 1924. (3) Magnus, 1910. (4) Anderson, 1930. (5) Ewald, 1914. (6) Linnavuori, 1922. (7) Nordmeyer, Bernoulli, 1907-8. (8) Simon-Rubemann, 1927. (9) Humpidge, 1883. (10) Nilson, Pettersson, 1880. (11) Magnus and Danz, 1926. (12) Kosef, 1911. (13) Moisson, Gautier, 1896. (14) Suhrmann, Lüde, 1924. (15) Andrews, 1848. (16) Lange, Simon, 1928. (17) Eckardt, Graefe, 1900. (18) Eastman, Rodebush. (19) Nernst, Lindemann, 1911. (20) Magnus, Hodler, 1926. (21) Dewar, 1913. (22) Hirsch, 1912. (23) Kneitsch. (24) Schübel, 1914. (25) Adler, 1903. (26) Eucken, Werth, 1930. (27) Richards, 1893. (28) Griffiths, 1894. (29) Clusius, Harteck, 1928. (30) Jaeger, Diesselhorst, 1900. (31) Bunsen, 1870. (32) Lange, 1924. (33) Estreicher, Straniewski, 1912. (34) Behn, 1900. (35) Kleinkhardt, 1927. (36) Hillebrand, 1876. (37) Keesom, 1927. (38) v. d. Eude. (39) Bidwell, 1925. (40) Laemmel, 1905. (41) Zulinski, 1928. (42) Simon, 1922, 1923. (43) Carpenter, Stoodley, 1930. (44) Simon, Zeidler, 1926. (45) Cooper, Langstroth, 1929. (46) Regnault, 1849, 1861. (47) White, 1918. (48) Dixon, Rodebush, 1927. (49) Noddeck, 1928. (50) Rengade, 1913. (51) Tammann. (52) Gronow. (53) Anderson, 1930. (54) Magnus, 1923. (55) Umino, 1926. (56) Mondain, Monval, 1926. (57) Dewar, 1905. (58) Wilgard, 1906. (59) Pirani, 1912. (60) Tilden, 1904. (61) Schmitz, 1903. (62) Wilson, 1883. (63) Rodebush, 1923. (64) Pionchon, 1886. (65) Zwikker, 1928. (66) Jaeger, Rosenbaum, 1930. (67) Blümcke, 1885. (68) Mache, 1897. (69) Clusius, Harteck, 1928.

References to Table 276: R, Regnault. L, Lorentz. T, Tomlinson. JD, Jaeger, Diesselhorst. M, Mazotto. S, Schüz. P, Person. W, Wachsmuth. Z. Zouloff. HM, H. Meyer. B, Batelli. GT, Gee and Terry. RW, R. W. Weber.

TABLE 275.—Specific Heat of Various Solids

Solid	Temperature °C	Specific heat	Authority See p. 289
Alloys:			
Bell metal	15–98	0.0858	R
Brass, red	0	.08991	L
" yellow	0	.08831	"
80 Cu + 20 Sn	14–98	.0862	R
Constantan, 60 Cu, 40 Ni	18	.0977	J D
" " "	100	.1018	"
German silver	0–100	.09464	T
Lipowitz alloy: 24.97 Pb + 10.13 Cd + 50.66 Bi + 14.24 Sn	5–50	.0345	M
Lipowitz alloy	100–150	.0426	"
Manganin: 84 Cu, 4 Ni, 12 Mn	18	.0973	J D
" " " "	100	.1004	"
Monel metal	20–1300	.127	—
Rose's alloy: 27.5 Pb + 48.9 Bi + 23.6 Sn	− 77–20	.0356	S
" "	20–89	.0552	"
Wood's alloy: 25.85 Pb + 6.99 Cd + 52.43 Bi + 14.73 Sn	5–50	.0352	M
Wood's alloy: (fluid)	100–150	.0426	"
Miscellaneous alloys:			
17.5 Sb + 29.9 Bi + 18.7 Zn + 33.9 Sn	20–99	.05657	R
37.1 Sb + 62.9 Pb	10–98	.03880	"
39.9 Pb + 60.1 Bi	16–99	.03165	P
63.8 Bi + 36.2 Sn	20–99	.04001	R
46.9 Bi + 53.1 Sn	20–99	.04504	"
Gas coal	20–1040	.3145	—
Glass, normal thermometer 16^{III}	19–100	.1988	W
" French hard thermometer		.1869	Z
" crown	10–50	.161	H M
" flint	10–50	.117	"
Ice	− 80	.350	B M
"	− 40	.434	"
"	− 20	.465	"
"	0	.487	"
India rubber (Para)	?–100	.481	G T
Mica	20	.10	—
Paraffin	− 20– + 3	.3768	R W
"	− 19– +20	.5251	"
"	0–20	.6939	"
"	35–40	.622	B
" fluid	60–63	.712	"
Woods	20	.327	—

TABLE 276.—Specific Heat of Water and of Mercury

Specific Heat of Water.							Specific Heat of Mercury.			
Temperature, °C.	Barnes.	Rowland.	Barnes-Regnault.	Temperature, °C.	Barnes	Barnes-Regnault.	Temperature, °C.	Specific Heat.	Temperature, °C.	Specific Heat.
−5	1.0155	-	-	60	0.9988	0.9994	0	0.03346	90	0.03277
0	1.0091	1.0070	1.0094	65	.9994	1.0004	5	.03340	100	.03269
+5	1.0050	1.0039	1.0053	70	1.0001	1.0015	10	.03335	110	.03262
10	1.0020	1.0016	1.0023	80	1.0014	1.0042	15	.03330	120	.03255
15	1.0000	1.0000	1.0003	90	1.0028	1.0070	20	.03325	130	.03248
20	0.9987	.9991	0.9990	100	1.0043	1.0101	25	.03320	140	.03241
25	.9978	.9989	.9981	120	-	1.0162	30	.03316	150	.0324
30	.9973	.9990	.9976	140	-	1.0223	35	.03312	170	.0322
35	.9971	.9997	.9974	160	-	1.0285	40	.03308	190	.0320
40	.9971	1.0006	.9974	180	-	1.0348	50	.03300	210	.0319
45	.9973	1.0018	.9976	200	-	1.0410	60	.03294	-	-
50	.9977	1.0031	.9980	220	-	1.0476	70	.03289	-	-
55	.9982	1.0045	.9985	-	-	-	80	.03284	-	-

Barnes's results: Phil. Trans. (A) 199, 1902; Phys. Rev. 15, 1902; 16, 1903. (H thermometer.)
Bousfield, Phil. Trans. A 211, p. 199, 1911. Barnes-Regnault's as revised by Peabody; Steam Tables.
The mercury data from 0° C to 80, Barnes-Cooke (H thermometer); from 90° to 140, mean of Winklemann, Naccari and Milthaler (air thermometer); above 140°, mean of Naccari and Milthaler.

TABLE 277.—Specific Heat of Various Liquids

Liquid.	Temp. °C.	Spec. heat.	Authority.
Alcohol, ethyl	−20	0.5053	R
" "	0	0.548	"
" "	40	0.648	"
Alcohol, methyl	5–10	0.590	"
" "	15–20	0.601	"
Anilin	15	0.514	G
"	30	0.520	"
"	50	0.529	"
Benzole, C_6H_6	10	0.340	H–D
" "	40	0.423	"
" C_6H_6	65	0.482	"
$CaCl_2$, sp. gr. 1.14	−15	0.764	DMG
" " " "	0	0.775	"
" " " "	+20	0.787	"
" " " 1.20	−20	0.695	"
" " " "	0	0.712	"
" " " "	+20	0.725	"
" " " 1.26	−20	0.651	"
" " " "	0	0.663	"
" " " "	+20	0.676	"
$CuSo_4$ + 50 H_2O	12–15	0.848	Pa
" + 200 "	12–14	0.951	"
" + 400 "	13–17	0.975	"
Diphenylamine, $C_{12}H_{11}N$	53	0.464	B
"	65	0.482	"

Liquid.	Temp. °C.	Spec. heat.	Authority.
Ethyl ether	0	0.529	R
Glycerine	15–50	0.576	E
KOH + $30H_2O$	18	0.876	TH
" + 100 "	18	0.975	"
NaOH + $50H_2O$	18	0.942	"
" + 100 "	18	0.983	"
NaCl + $10H_2O$	18	0.791	"
" + 200 "	18	0.978	"
Naphthalene, $C_{10}H_8$	80–85	0.396	B
"	90–95	0.409	"
Nitrobenzole	14	0.350	A
"	28	0.362	"
Oils: castor	—	0.434	W
citron	5.4	0.438	HW
olive	6.6	0.471	"
sesame	—	0.387	W
turpentine	0	0.411	R
Petroleum	21–58	0.511	Pa
Sea water, sp. gr. 1.0043	17.5	0.980	"
" " " " 1.0235	17.5	0.938	"
" " " " 1.0463	17.5	0.903	"
Toluol, C_6H_8	10	0.364	H–D
"	65	0.490	"
"	85	0.534	"
$ZnSO_4$ + 50 H_2O	20–52	0.842	Ma
" + 200 "	20–52	0.952	"

References: (A) Abbot; (B) Batelli; (E) Emo; (G) Griffiths; (DMG) Dickinson, Mueller, and George; (H–D) de Heen and Deruyts; (Ma) Marignac; (Pa) Pagliani; (R) Regnault; (Th) Thomsen; (W) Wachsmuth; (Z) Zouloff; (HW) H. F. Weber.

TABLE 278.—Specific Heat of Liquid Ammonia under Saturation Conditions

Expressed in Calories$_{20}$ per Gram per Degree C. Osborne and van Dusen, Bul. Bureau of Standards, 1918.

Temp. °C	0	1	2	3	4	5	6	7	8	9
−40	1.062	1.061	1.060	1.059	1.058	1.058	1.057	1.056	1.055	1.055
−30	1.070	1.069	1.068	1.067	1.066	1.065	1.064	1.064	1.063	1.062
−20	1.078	1.077	1.076	1.075	1.074	1.074	1.073	1.072	1.071	1.070
−10	1.088	1.087	1.086	1.085	1.084	1.083	1.082	1.081	1.080	1.079
− 0	1.099	1.098	1.097	1.096	1.094	1.093	1.092	1.091	1.090	1.089
+ 0	1.099	1.100	1.101	1.103	1.104	1.105	1.106	1.108	1.109	1.110
+10	1.112	1.113	1.114	1.116	1.117	1.118	1.120	1.122	1.123	1.125
+20	1.126	1.128	1.129	1.131	1.132	1.134	1.136	1.137	1.139	1.141
+30	1.142	1.144	1.146	1.148	1.150	1.152	1.154	1.156	1.158	1.160
+40	1.162	1.164	1.166	1.169	1.171	1.173	1.176	1.178	1.181	1.183

TABLE 279.—Heat Content of Saturated Liquid Ammonia

Heat content = $H = \epsilon + pv$, where ϵ is the internal or intrinsic energy. Osborne and van Dusen, Bul. Bureau of Standards, 1918.

Temperature	−50°	−40°	−30°	−20°	−10°	0°	+10°	+20°	+30°	+40°	+50°
$H = \epsilon + pv$	−53.8	−43.3	−32.6	−21.8	−11.0	0.0	+11.1	+22.4	−33.9	−45.5	−57.4

TABLE 280.—Specific Heat of Minerals and Rocks

Substance.	Temperature ° C.	Specific Heat.	Reference.	Substance.	Temperature ° C.	Specific Heat.	Reference.
Andalusite	0–100	0.1684	1	Rock-salt	13–45	0.219	6
Anhydrite, $CaSO_4$	0–100	.1753	1	Serpentine	16–98	.2586	2
Apatite	15–99	.1903	2	Siderite	9–98	.1934	4
Asbestos	20–98	.195	3	Spinel	15–47	.194	6
Augite	20–98	.1931	3	Talc	20–98	.2092	3
Barite, $BaSO_4$	10–98	.1128	4	Topaz	0–100	.2097	1
Beryl	15–99	.1979	2	Wollastonite	19–51	.178	6
Borax, $Na_2B_4O_7$ fused	16–98	.2382	4	Zinc blende, ZnS	0–100	.1146	1
Calcite, $CaCO_3$	0–50	.1877	1	Zircon	21–51	.132	6
" "	0–100	.2005	1	Rocks:			
" "	0–300	.2204	1	Basalt, fine, black	12–100	.1996	6
Cassiterite SnO_2	16–98	.0933	4	" " "	20–470	.199	9
Chalcopyrite	15–99	.1291	2	" " "	470–750	.243	9
Corundum	9–98	.1976	4	" " "	750–880	.626	9
Cryolite, $Al_2F_6.6NaF$	16–99	.2522	2	" " "	880–1190	.323	9
Fluorite, CaF_2	15–99	.2154	4	Dolomite	20–98	.222	3
Galena, PbS	0–100	.0466	5	Gneiss	17–99	.196	10
Garnet	16–100	.1758	2	"	17–213	.214	10
Hematite, Fe_2O_3	15–99	.1645	2	Granite	12–100	.192	7
Hornblende	20–98	.1952	3	Kaolin	20–98	.224	3
Hypersthene	20–98	.1914	3	Lava, Aetna	23–100	.201	11
Labradorite	20–98	.1949	3	" "	31–776	.259	11
Magnetite	18–45	.156	6	" Kilauea	25–100	.197	11
Malachite, $Cu_2CO_4H_2O$	15–99	.1763	2	Limestone	15–100	.216	12
Mica (Mg)	20–98	.2061	3	Marble	0–100	.21	–
" (K)	20–98	.2080	3	Quartz sand	20–98	.191	3
Oligoclase	20–98	.2048	3	Sandstone	–	.22	–
Orthoclase	15–99	.1877	2				
Pyrolusite, MnO_2	17–48	.159	6				
Quartz, SiO_2	12–100	.188	7				
" "	0	.1737	8				
" "	350	.2786	8				
" "	400–1200	.305	8				

1 Lindner. 6 Kopp. 11 Bartoli.
2 Oeberg. 7 Joly. 12 Morano.
3 Ulrich. 8 Pionchon.
4 Regnault. 9 Roberts-Austen, Rücker.
5 Tilden. 10 R. Weber.

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

TABLE 281.—Specific Heat of Silicates

Silicate.	Mean specific heats. 0° C to				True specific heats. at				
	100°	500°	900°	1400°	0° C	100°	500°	1000°	1300°
Albite	.1948	.2363	.2561	–	.178	.211	.269	.294	–
" glass	.1977	.2410	.2640	–	–	–	–	–	–
Amphibole, Mg. silicate	.2033	.2461	.2661	.2731*	.185	.219	.279	.304	–
" glass	.2040	.2474	–	–	–	–	–	–	–
Andesine	.1925	.2330	.2525	–	–	–	.265	–	–
" glass	.1934	–	.2615	–	–	–	–	–	–
Anorthite	.1901	.2296	02481	.2674	.174	.205	.260	.286	.318
" glass	.1883	.2305	–	–	–	–	–	–	–
Cristobalite	.1883	.2426	.2568	.2680	–	–	–	–	–
Diopside	.1924	.2314	.2500	.2604†	.176	.207	.262	.284	–
" glass	.1939	.2332	–	–	–	–	–	–	–
Microcline	.1871	.2262	.2450	–	.171	.201	.258	.279	–
" glass	.1919	.2321	.2514	.2598*	.176	.206	.264	.299	–
Pyroxene	.2039	.2484	–	–	–	–	–	–	–
Quartz	.1868	.2379	.2596	.2640*	.168	.204	.294	.285	–
Silica glass	.1845	.2302	.2512	–	.166	.202	.266	.29	–
Wollastonite	–	–	.2344	–	–	–	–	–	–
" glass	.1852	.2206	–	–	–	–	–	–	–
" pseudo	.1844	.2170	.2324	.2448	.171	.197	.243	.262	.272

*0°–1100°; †0°–1250°; Taken from White, Am. J. Sc. 47, 1, 1919.

Table 282
SPECIFIC HEAT OF GASES AND VAPORS

Substance.	Range of temp. °C	Sp. ht. constant pressure.	Authority.	Range of temp. °C	Mean ratio of specific heats. C_p/C_v.	Authority.
Acetone, C_3H_6O	26–110	0.3468	Wiedemann.			
Air	−30–+10	0.2377	Regnault.	20	1.4011	Moody.
"	0–200	0.2375	"	−79.3	1.405	Koch, 1907.
"	20–440	0.2366	Holborn and	−79.3	2.333	" 200 atm
"	20–630	0.2429	Austin.	0	1.828	" " "
"	20–800	0.2430	"	500	1.399	Fürstenau.
Alcohol, C_2H_5OH	108–220	0.4534	Regnault.	53	1.133	Jaeger.
" "	—	—	—	100	1.134	Stevens.
" CH_3OH	101–223	0.4580	Regnault.	100	1.256	"
Ammonia	23–100	0.5202	Wiedemann.	0	1.3172	Wüllner.
"	27–200	0.5356	"	100	1.2770	"
Argon	20–90	0.1233	Dittenberger.	0	1.667	Niemeyer.
Benzene, C_6H_6	34–115	0.2990	Wiedemann.	20	1.403	Pagliani.
" "	35–180	0.3325	"	60	1.403	"
" "	116–218	0.3754	Regnault.	99.7	1.105	Stevens.
Bromine	83–228	0.0555	"	20–388	1.293	Strecker.
Carbon dioxide, CO_2	−28–+7	0.1843	"	4–11	1.2995	Lummer and
" " "	15–100	0.2025	"			Pringsheim.
" " "	11–214	0.2169	"	0	1.3003	Moody, 1912.
" monoxide, CO	23–99	0.2425	Wiedemann.	0	1.403	Wüllner.
" " "	26–198	0.2426	"	100	1.395	"
" disulphide, CS_2	86–190	0.1596	Regnault.	3–67	1.205	Beyme.
Chlorine	16–343	0.1125	Strecker.	0	1.336	Martini.
Chloroform, $CHCl_3$	27–118	0.1441	Wiedemann.	22–78	1.102	Beyme.
" "	28–189	0.1489	"	99.8	1.150	Stevens.
Ether, $C_4H_{10}O$	69–224	0.4797	Regnault.	42–45	1.029	Müller.
" "	25–111	0.4280	Wiedemann.	12–20	1.024	Low, 1894.
Helium	—	—	—	0	1.64	Mean, Jeans
Hydrochloric acid, HCl	13–100	0.1940	Strecker.	20	1.389	Strecker.
" " "	22–214	0.1867	Regnault.	100	1.400	"
Hydrogen	−28–+9	3.3996	"	4–16	1.4080	Lummer and
"	12–198	3.4090	"			Pringsheim.
"	21–100	3.4100	Wiedemann.	—	1.419	Hartmann.
" sulphide, H_2S	20–206	0.2451	Regnault.	—	1.324	Capstick.
Krypton	—	—	—	19	1.666	Ramsay, '12.
Mercury	—	—	—	310	1.666	Kundt and Warburg.
Methane, CH_4	18–208	0.5929	Regnault.	11–30	1.316	Müller.
Neon	—	—	—	19	1.642	Ramsay, '12
Nitrogen	0–200	0.2438	Regnault.	—	1.41	Cazin.
"	20–440	0.2419	Holborn and	—	1.405	Masson.
"	20–630	0.2464	Austin.			
"	20–800	0.2497	"			
Nitric oxide, NO	13–172	0.2317	Regnault.	—	1.394	"
Nitrogen tetroxide, NO_2	27–67	1.625	Berthelot and	—	1.31	Natanson.
" " "	27–150	1.115	Olger.			
" " "	27–280	0.65	"			
Nitrous oxide, N_2O	16–207	0.2262	Regnault.	0	1.311	Wüllner.
" " "	26–103	0.2126	Wiedemann.	100	1.272	"
" " "	27–206	0.2241	"	—	1.324	Leduc, '98.
Oxygen	13–207	0.2175	Regnault.	5–14	1.3977	Lummer and
"	20–440	0.2240	Holborn and			Pringsheim.
"	20–630	0.2300	Austin.			
Sulphur dioxide, SO_2	16–202	0.1544	Regnault.	16–34	1.256	Müller.
Water vapor, H_2O	0	0.4655	Thiesen.	78	1.274	Beyme.
" " "	100	0.421	"	94	1.33	Jaeger.
" " "	180	0.51	"	100	1.305	Makower.
Xenon	—	—	—	19	1.666	Ramsay, '12.

Table 283

LATENT HEAT OF FUSION

The values indicated by * were chosen by Dr. W. P. White of the Carnegie Geophysical Laboratory.

Element	Temp. °C	Cal./g	Ref.	Element	Temp. °C	Cal./g	Ref.
Al	657	93	*	Li	....	33	(6)
Sb	630	39	†	Mg	650	72	*
A	−190	6.64	(1)	Hg	−387	2.78	*
Bi	269	12.8	*	Ni	1450	73	(7)
Br	−7	16	(2)	N	−210	6.1	†
Cd	321	12.8	†	O	−219	3.33	†
Cs	285	3.8	(3)	K	58	14.6	†
Ca	809	78	(4)	Rb	39	6.1	†
Cr	1600	70	(5)	Se	217	13	(8)
Co	1489	64	†	Ag	960	25.9	*
Cu	1083	49.3	*	Na	98	27	†
Au	1063	15.9	*	S, mc.	115	9.3	†
H	−249	14	†	Sn	232	14.4	*
Fe	1528	49.3	*	Zn	420	26.6	*
Pb	327	6	*				

* Via Dr. W. P. White. † Mean of several. (1) Eucken-Hauck, 1928. (2) Regnault. (3) Rengade, 1913. (4) Zalesinski, Zulinski, 1928. (5) Umino, 1926. (6) Thun. (7) White, 1921. (8) Monval.

Compound	Cal./g	Ref.	Compound	Cal./g	Ref.
$BaCl_2$	28	Plato, 1906	Anorthite	104	Bowen, 1922
$CaCl_2$	54	" "	Albite	48.5	" "
KCl	86	" "	Diopside	100	White
NaCl	124	" "	Quartz	50	Sosman
$SrCl_2$	26	" "	Cristobalite	305	Kracek, 1930

Substance	Composition	T	Cal./g	Authority
Alloys: 30.5Pb + 69.5Sn	$PbSn_4$	183	17	Spring
36.9Pb + 63.1Sn	$PbSn_3$	179	15.5	"
63.7Pb + 36.3Sn	PbSn	177.5	11.6	"
77.8Pb + 22.2Sn	Pb_2Sn	176.5	9.54	"
Britannia metal, 9Sn + 1Pb	....	236	28.0[1]	Ledebur
Rose's alloy, 24Pb + 27.3Sn + 48.7Bi	....	98.8	6.85	Mazzotto
Wood's alloy {25.8Pb + 14.7Sn + 52.4Bi + 7Cd}	....	75.5	8.40	"
Ammonia	NH_3	−75	108	Massol
Benzole	C_6H_6	5.4	30.6	Mean
Ice	H_2O	0	79.63	Dickinson, Harper, Osborne[2]
"	"	0	79.59	Smith[3]
" (from sea water)	{H_2O + 3.535 of solids}	−8.7	54.0	Pettersson
Naphthalene	$C_{10}H_8$	79.87	35.62	Pickering
Potassium nitrate	KNO_3	333.5	48.9	Person
Phenol	C_6H_6O	25.37	24.93	Pettersson
Paraffin	....	52.40	35.10	Batelli
Sodium	Na	97	31.7	Joannis
" nitrate	$NaNO_3$	305.8	64.87	"
" phosphate	{Na_2HPO_4 $12H_2O$}	36.1	66.8	"
Spermaceti	....	43.9	36.98	Batelli
Wax (bees)	....	61.8	42.3	Mean

[1] Total heat from 0°C.
[2] Bureau of Standards, 1913, in terms of 15° calorie.
[3] 1903, based on electrical measurements, assuming mechanical equivalent = 4.187, and in terms of the value of the international volt in use after 1911.

TABLE 284.—Latent Heat of Vaporization of Elements

Element	t°C	Cal./g	Ref.	Element	t°C	Cal./g	Ref.
Sb	755	320	1	I	174	24	7
A	1 atm.	37.6	2	Kr	−151	28	8
Ba, l	1537	308	3	Pb	1170	175	1
Bi	920	190	1	Li	1336	511	3
Br	60±	43	†	Mg	1110	136	†
Cd	778	240	4	Hg	358	71	†
Ca	143.9	101	3	N	−195.6	476	9
Cl	− 63	63	†	O_2	−182.9	50.9	9
Fl	−188.2	40.5	5	Sr	1336	410	11
He	−271.3	5.6	6	X	−108.6	25.1	3
H_2	−253	108	†	Zn	918	475	4

† Mean; (1) Tait, 1914. (2) Eucken, 1916. (3) Hartmann, Schneider, 1929. (4) Egerton, 1917. (5) Cady Hildebrand, 1930. (6) Dana, Onnes, 1925. (7) Favre, Silbermann (old). (8) Peters, Weil, 1930. (9) Alt, 1906. (10) Peters, Weil, 1930.

TABLE 285.—Latent Heat of Vaporization of Liquids

Substance	Formula	t°C	Latent heat vaporization cal./g	Total heat from 0°C cal./g	Authority
Alcohol: Ethyl	C_2H_6O	78.1	205	255	Wirtz
"	"	0	236	236	Regnault
"	"	100	...	267	"
"	"	150	...	285	"
Methyl	CH_4O	64.5	267	307	Wirtz
"	"	0	289	...	Ramsay and Young
"	"	100	246	...	" " "
"	"	150	206	...	" " "
"	"	200	152	...	" " "
"	"	238.5	44.2	...	" " "
Aniline	C_6H_7N	184	110	...	Mean
Benzene	C_6H_6	80.1	92.9	127.9	Wirtz
Carbon dioxide, solid	CO_2	...	...	138.7	Favre
" " liquid	"	−25	72.23	...	Cailletet and Mathias
" " "	"	0	57.48	...	" " "
" " "	"	12.35	44.97	...	Mathias
" " "	"	22.04	31.8	...	"
" " "	"	30.82	3.72	...	"
" disulphide	CS_2	46.1	83.8	94.8	Wirtz
" "	"	0	90	90	Regnault
" "	"	100	...	100.5	"
Chloroform	$CHCl_3$	60.9	58.5	72.8	Wirtz
Ether	$C_4H_{10}O$	34.5	88.4	107	"
"	"	0	94	94	Regnault
"	"	50	...	115.1	"
"	"	120	...	140	"
Ethyl bromide	C_2H_5Br	38.2	60.4	...	Wirtz
" chloride	C_2H_5Cl	12.5	...	98	Regnault
" iodide	C_2H_5I	71	47	...	Mean
Heptane	C_7H_{16}	90	77.8	...	Young
Hexane	C_6H_{14}	70	79.2	...	"
Octane	C_8H_{18}	130	70.0	...	"
Pentane	C_5H_{12}	30	85.8	...	"
Sulphur dioxide	SO_2	0	91.2	...	Cailletet and Mathias
" "	"	65	68.4	...	" " "
Toluol	C_7H_8	111	86.0	...	Mean
Turpentine	$C_{10}H_{10}$	159.3	74.04	...	Brix

TABLE 286.—Latent and Total Heat of Vaporization, Formulae

r = latent heat of vaporization at $t°$ C; H = total heat from fluid at 0° to vapor at $t°$ C. $T°$ refers to Kelvin scale. Same units as preceding table.

Substance	Formula	Range		Authority
Acetone, C_3H_6O	$H = 140.5 + 0.36644t - 0.000516t^2$	−3° to	147°	R
	$= 139.9 + 0.23356t + 0.00055358t^2$	−3	147	W
	$r = 139.9 - 0.27287t + 0.0001571t^2$	−3	147	W
Benzene C_6H_6	$H = 109.0 + 0.24429t - 0.0001315t^2$	7	215	R
Carbon dioxide	$r^2 = 118.485(31 - t) - 0.4707(31 - t)^2$	−25	31	C
Carbon bisulphide, CS_2	$H = 90.0 + 0.14601t - 0.0004123t^2$	−6	143	R
	$H = 89.5 + 0.16993t - 0.0010161t^2 + 0.0_5342t^3$	−6	143	W
	$r = 89.5 - 0.06530t - 0.0010976t^2 + 0.0_5342t^3$	−6	143	W
Carbon tetrachloride, CCl_4	$H = 52.0 + 0.14625t - 0.000172t^2$	8	163	R
	$H = 51.9 + 0.17867t - 0.0009599t^2 + 0.0_53733t^3$	8	163	W
	$r = 51.9 - 0.01931t - 0.0010505t^2 + 0.0_53733t^3$	8	163	W
Chloroform, $CHCl_3$	$H = 67.0 + 0.1375t$	−5	159	R
	$H = 67.0 + 0.14716t - 0.0000937t^2$	−5	159	W
	$r = 67.0 - 0.08519t - 0.0001444t^2$	−5	159	W
Ether, $C_4H_{10}O$	$H = 94.0 + 0.45000t - 0.0005556t^2$	−4	121	R
	$r = 94.0 - 0.07900t - 0.0008514t^2$	−4	121	R
Molybdenum	$r = 177000 - 2.5T$ (cal/g-atom)	——		L
Nitrogen, N_2	$r = 68.85 - 0.2736T$	——		A
Nitrous oxide, N_2O	$r^2 = 131.75(36.4 - t) - 0.928(36.4 - t)^2$	−20	36	C
Oxygen, O_2	$r = 69.67 - 0.2080T$	——		A
Platinum	$r = 128000 - 2.5T$ (cal/g-atom)	——		L
Sulphur dioxide	$r = 91.87 - 0.3842t - 0.000340t^2$	0	20	M
Tungsten	$r = 217800 - 1.8T$ (cal/g-atom)	——		L
Water, H_2O	$H = 638.9 + 0.3745(t - 100) - 0.00099(t - 100)^2$	——		D
	$r = 94.210(365 - t)^{0.31249}$ (See Table 290)	0	100	H

R, Regnault; W, Winkelmann; C, Cailletet and Mathias; A, Alt.; D, Davis; H, Henning; L, Langmuir.

TABLE 287.—Latent Heat of Vaporization of Ammonia

CALORIES PER GRAM

°C	0	1	2	3	4	5	6	7	8	9
−40	331.7	332.3	333.0	333.6	334.3	334.9	335.5	336.2	336.8	337.5
−30	324.8	325.5	326.2	326.9	327.6	328.3	329.0	329.7	330.3	331.0
−20	317.6	318.3	319.1	319.8	320.6	321.3	322.0	322.7	323.4	324.1
−10	309.9	310.7	311.5	312.2	313.0	313.8	314.6	315.3	316.1	316.8
− 0	301.8	302.6	303.4	304.3	305.1	305.9	306.7	307.5	308.3	309.1
+ 0	301.8	300.9	300.1	299.2	298.4	297.5	296.6	295.7	294.9	294.0
+10	293.1	292.2	291.3	290.4	289.5	288.6	287.6	286.7	285.7	284.8
+20	283.8	282.8	281.8	280.9	279.9	278.9	277.9	276.9	275.9	274.9
+30	273.9	272.8	271.8	270.7	269.7	268.6	267.5	266.4	265.3	264.2
+40	263.1	262.0	260.8	259.7	258.5	257.4	256.2	255.0	253.8	252.6

Osborne and van Dusen, Bul. Bureau Standards, 14, p. 439, 1918.

TABLE 288.—"Latent Heat of Pressure Variation" of Liquid Ammonia

When a fluid undergoes a change of pressure, there occurs a transformation of energy into heat or vice versa, which results in a change of temperature of the substance unless a like amount of heat is abstracted or added. This change expressed as the heat so transformed per unit change of pressure is the "latent heat of pressure variation." It is expressed below as Joules per gram per kg cm². Osborne and van Dusen, *loc. cit.*, p. 433, 1918.

Temperature °C	−44.1	−39.0	−24.2	−0.2	+16.5	+26.5	+35.4	+40.3
Latent heat	−.055	−.057	−.068	−.088	−.107	−.123	−.140	−.150

TABLE 289

THERMAL PROPERTIES OF SATURATED WATER AND STEAM

(Osborne, Stimson, Fiock, Bur. Standards Journ. Res., 5, 411, 1930.)

Accuracy: It is estimated that there is only one chance in 100 that the values given for H differ from the truth by as much as one part in 2000; it is equally unlikely that the values for L and H' are as much as 1.5 joules/g from the truth in the range of the experiments, 100°-270°C.

Temperature, °C	Heat content of liquid, H	Latent heat, L	Heat content of vapor, H'	Entropy— of liquid Φ	Entropy— of vapor Φ'
	Int. joules/g	Int. joules/g	Int. joules/g	Int. joules/g°C	Int. joules/g°C
0	0	2494.02	2494.02	0	9.132
10	42.02	2472.26	2514.28	.1511	8.884
20	83.83	2450.17	2534.00	.2962	8.656
30	125.59	2427.73	2553.32	.4363	8.446
40	167.34	2404.90	2572.24	.5719	8.253
50	209.11	2381.64	2590.75	.7032	8.074
60	250.90	2357.91	2608.81	.8305	7.909
70	292.75	2333.65	2626.40	.9543	7.756
80	334.66	2308.32	2643.48	1.0746	7.613
90	376.65	2283.38	2660.03	1.1918	7.480
100	418.75	2257.24	2675.99	1.3064	7.356
110	460.97	2230.35	2691.32	1.4177	7.240
120	503.36	2202.65	2706.01	1.5268	7.130
130	545.93	2174.04	2719.97	1.6335	7.027
140	588.71	2144.44	2733.15	1.7381	6.929
150	631.75	2113.76	2745.51	1.8407	6.837
160	675.06	2081.89	2756.95	1.9416	6.749
170	718.66	2048.72	2767.38	2.0406	6.664
180	762.72	2014.10	2776.82	2.1384	6.584
190	807.15	1977.89	2785.04	2.2348	6.506
200	852.02	1939.93	2791.95	2.3299	6.430
210	897.35	1900.00	2797.35	2.4239	6.357
220	943.24	1857.89	2801.13	2.5169	6.285
230	989.75	1813.33	2803.08	2.6091	6.213
240	1036.97	1766.02	2802.99	2.7007	6.143
250	1084.97	1715.59	2800.56	2.7919	6.072
260	1133.87	1661.60	2795.47	2.8828	6.000
270	1184.32	1603.51	2787.83	2.9746	5.927

TABLE 290

PROPERTIES OF SATURATED STEAM

Metric and Common Units 0° to 220° C

Reprinted by permission of the author and publishers from "Tables of the Properties of Steam," Cecil H. Peabody, 8th edition, rewritten in 1909. Calorie used is heat required to raise 1 Kg. water from 15° to 16° C. B. T. U. is heat required to raise 1 pd. water from 62° to 63° F. Mechanical Equiv. of heat used, 778 ft. pds. or 427 m. Kg. Specific heats, see Barnes-Regnault-Peabody results, p. 227. Heat of Liquid, q. heat required to raise 1 Kg. (1 lb.) to corresponding temperature from 0° C. Heat of vaporization, r. heat required to vaporize 1 Kg. (1 lb.) at corresponding temperature to dry saturated vapor against corresponding pressure; see Henning, Ann. der Phys., 21, p. 849, 1906. Total Heat, H = r + q, see Davis, Tr. Am. Soc. Mech. Eng., 1908.

Temperature Degrees Centigrade.	Pressure.			Heat of the Liquid.		Heat of Vaporization.		Heat Equivalent of Internal Work.		Temperature Degrees Fahrenheit.
t.	Mm of Mercury. p.	Kg per sq. cm p.	Pds. per sq. in. p.	Calories. q.	B. T. U. q.	Calories. r.	B. T. U. r.	Calories. ρ.	B. T. U. ρ.	t.
0	4.579	0.00623	0.0886	0.00	0.0	595.4	1071.7	565.3	1017.5	32.0
5	6.541	.00889	.1265	5.04	9.1	592.8	1067.1	562.2	1011.9	41.0
10	9.205	.01252	.1780	10.06	18.1	590.2	1062.3	559.0	1006.2	50.0
15	12.779	.01737	.2471	15.06	27.1	587.6	1057.6	555.9	1000.5	59.0
20	17.51	.02381	.3386	20.06	36.1	584.9	1052.8	552.7	994.8	68.0
25	23.69	.03221	.4581	25.05	45.1	582.3	1048.1	549.5	989.1	77.0
30	31.71	.04311	.6132	30.04	54.1	579.6	1043.3	546.3	983.4	86.0
35	42.02	.05713	.8126	35.03	63.1	576.9	1038.5	543.1	977.6	95.0
40	55.13	.07495	1.0661	40.02	72.0	574.2	1033.5	539.9	971.7	104.0
45	71.66	.09743	1.3858	45.00	81.0	571.3	1028.4	536.5	965.7	113.0
50	92.30	.12549	1.7849	49.99	90.0	568.4	1023.2	533.0	959.6	122.0
55	117.85	.16023	2.279	54.98	99.0	565.6	1018.1	529.7	953.5	131.0
60	149.19	.20284	2.885	59.97	108.0	562.8	1013.1	526.4	947.5	140.0
65	187.36	.2547	3.623	64.98	117.0	559.9	1007.8	523.0	941.3	149.0
70	233.53	.3175	4.516	69.98	126.0	556.9	1002.5	519.5	935.0	158.0
75	289.0	.3929	5.589	74.99	135.0	554.0	997.3	516.0	928.8	167.0
80	355.1	.4828	6.867	80.01	144.0	551.1	991.9	512.6	922.6	176.0
85	433.5	.5894	8.383	85.04	153.1	548.1	986.5	509.1	916.3	185.0
90	525.8	.7149	10.167	90.07	162.1	544.9	980.9	505.4	909.9	194.0
91	546.1	.7425	10.560	91.08	163.9	544.3	979.8	504.7	908.5	195.8
92	567.1	.7710	10.966	92.08	165.7	543.7	978.7	504.0	907.2	197.6
93	588.7	.8004	11.384	93.09	167.5	543.1	977.6	503.3	906.0	199.4
94	611.0	.8307	11.815	94.10	169.3	542.5	976.5	502.6	904.7	201.2
95	634.0	.8620	12.260	95.11	171.2	541.9	975.4	501.9	903.4	203.0
96	657.7	.8942	12.718	96.12	173.0	541.2	974.2	501.1	902.1	204.8
97	682.1	.9274	13.190	97.12	174.8	540.6	973.1	500.4	900.8	206.6
98	707.3	.9616	13.678	98.13	176.6	539.9	971.9	499.6	899.4	208.4
99	733.3	.9970	14.180	99.14	178.5	539.3	970.8	498.9	898.2	210.2
100	760.0	1.0333	14.697	100.2	180.3	538.7	969.7	498.2	896.9	212.0
101	787.5	1.0707	15.229	101.2	182.1	538.1	968.5	497.5	895.5	213.8
102	815.9	1.1093	15.778	102.2	183.9	537.4	967.3	496.8	894.1	215.6
103	845.1	1.1490	16.342	103.2	185.7	536.8	966.2	496.1	892.9	217.4
104	875.1	1.1898	16.923	104.2	187.6	536.2	965.1	495.4	891.6	219.2
105	906.1	1.2319	17.522	105.2	189.4	535.6	964.0	494.7	890.3	221.0
106	937.9	1.2752	18.137	106.2	191.2	534.9	962.8	493.9	889.0	222.8
107	970.6	1.3196	18.769	107.2	193.0	534.2	961.6	493.1	887.6	224.6
108	1004.3	1.3653	19.420	108.2	194.8	533.6	960.5	492.4	886.3	226.4
109	1038.8	1.4123	20.089	109.3	196.7	532.9	959.3	491.6	885.0	228.2
110	1074.5	1.4608	20.777	110.3	198.5	532.3	958.1	490.9	883.6	230.0
111	1111.1	1.5106	21.486	111.3	200.3	531.6	956.9	490.2	882.3	231.8
112	1148.7	1.5617	22.214	112.3	202.1	530.9	955.7	489.4	880.9	233.6
113	1187.4	1.6144	22.962	113.3	203.9	530.3	954.5	488.7	879.5	235.4
114	1227.1	1.6684	23.729	114.3	205.8	529.6	953.3	487.9	878.2	237.2
115	1267.9	1.7238	24.518	115.3	207.6	528.9	952.1	487.1	876.8	239.0
116	1309.8	1.7808	25.328	116.4	209.4	528.2	950.8	486.3	875.4	240.8
117	1352.8	1.8393	26.160	117.4	211.2	527.5	949.5	485.5	873.9	242.6
118	1397.0	1.8993	27.015	118.4	213.0	526.9	948.4	484.8	872.6	244.4
119	1442.4	1.9611	27.893	119.4	214.9	526.2	947.2	484.0	871.3	246.2

PROPERTIES OF SATURATED STEAM

Metric and Common Units 0° to 220° C

If a is the reciprocal of the Mechanical Equivalent of Heat, p the pressure, s and σ the specific volumes of the liquid and the saturated vapor, s —.σ, the change of volume, then the heat equivalent of the external work is Apu = Ap(s — σ). Heat equivalent of internal work, ρ = r — Apu. For experimental sp. vols. see Knoblauch, Linde and Klebe, Mitt. über Forschungarbeiten, 21, p. 33, 1905. Entropy = S dQ/T, where dQ = amount of heat added at absolute temperature T. For pressures of saturated steam see Holborn and Henning, Ann. der Phys. 26, p. 833, 1908; for temperatures above 205° C corrected from Regnault.

Temperature Degrees Centigrade. t.	Heat Equivalent of External Work. Calories. Apu.	B.T.U. Apu.	Entropy of the Liquid. θ	Entropy of Evaporation. $\frac{r}{T}$	Specific Volume. Cubic Meters per Kilogram s	Cubic Feet per Pound. s	Density. Kilograms per Cubic Meter. $\frac{1}{s}$	Pounds per Cubic Foot. $\frac{1}{s}$	Temperature Degrees Fahrenheit. t.
0	30.1	54.2	0.0000	2.1804	206.3	3304.	0.00485	0.000303	32.0
5	30.6	55.2	.0183	2.1320	147.1	2356.	.00680	.000424	41.0
10	31.2	56.1	.0361	2.0850	106.3	1703.	.00941	.000587	50.0
15	31.7	57.1	.0537	2.0396	77.9	1248.	.01283	.000801	59.0
20	32.2	58.0	.0709	1.9959	57.8	926.	.01730	.001080	68.0
25	32.8	59.0	.0878	1.9536	43.40	695.	.02304	.001439	77.0
30	33.3	59.9	.1044	1.9126	32.95	528.	.03035	.001894	86.0
35	33.8	60.9	.1207	1.8728	25.25	404.7	.03960	.002471	95.0
40	34.3	61.8	.1368	1.8341	19.57	313.5	.0511	.003190	104.0
45	34.8	62.7	.1526	1.7963	15.25	244.4	.0656	.004092	113.0
50	35.4	63.6	.1682	1.7597	12.02	192.6	.0832	.00519	122.0
55	35.9	64.6	.1835	1.7242	9.56	153.2	.1046	.00653	131.0
60	36.4	65.6	.1986	1.6899	7.66	122.8	.1305	.00814	140.0
65	36.9	66.5	.2135	1.6563	6.19	99.2	.1615	.01008	149.0
70	37.4	67.4	.2282	1.6235	5.04	80.7	.1984	.01239	158.0
75	38.0	68.5	.2427	1.5918	4.130	66.2	.2421	.01510	167.0
80	38.5	69.3	.2570	1.5609	3.404	54.5	.2938	.01835	176.0
85	39.0	70.2	.2711	1.5307	2.824	45.23	.3541	.02211	185.0
90	39.5	71.0	.2851	1.5010	2.358	37.77	.4241	.02648	194.0
91	39.6	71.3	.2879	1.4952	2.275	36.45	.4395	.02743	195.8
92	39.7	71.5	.2906	1.4894	2.197	35.19	.4552	.02842	197.6
93	39.8	71.6	.2934	1.4836	2.122	34.00	.4713	.02941	199.4
94	39.9	71.8	.2961	1.4779	2.050	32.86	.4878	.03043	201.2
95	40.0	72.0	.2989	1.4723	1.980	31.75	.505	.03149	203.0
96	40.1	72.1	.3016	1.4666	1.913	30.67	.523	.03260	204.8
97	40.2	72.3	.3043	1.4609	1.849	29.63	.541	.03375	206.6
98	40.3	72.5	.3070	1.4552	1.787	28.64	.560	.03492	208.4
99	40.4	72.6	.3097	1.4496	1.728	27.69	.579	.03611	210.2
100	40.5	72.8	.3125	1.4441	1.671	26.78	.598	.03734	212.0
101	40.6	73.0	.3152	1.4386	1.617	25.90	.618	.03861	213.8
102	40.6	73.2	.3179	1.4330	1.564	25.06	.639	.03990	215.6
103	40.7	73.3	.3205	1.4275	1.514	24.25	.661	.04124	217.4
104	40.8	73.5	.3232	1.4220	1.465	23.47	.683	.04261	219.2
105	40.9	73.7	.3259	1.4165	1.419	22.73	.705	.04400	221.0
106	41.0	73.8	.3286	1.4111	1.374	22.01	.728	.04543	222.8
107	41.1	74.0	.3312	1.4057	1.331	21.31	.751	.04692	224.6
108	41.2	74.2	.3339	1.4003	1.289	20.64	.776	.04845	226.4
109	41.3	74.3	.3365	1.3949	1.248	19.99	.801	.0500	228.2
110	41.4	74.5	.3392	1.3895	1.209	19.37	.827	.0516	230.0
111	41.4	74.6	.3418	1.3842	1.172	18.77	.853	.0533	231.8
112	41.5	74.8	.3445	1.3789	1.136	18.20	.880	.0550	233.6
113	41.6	75.0	.3471	1.3736	1.101	17.64	.908	.0567	235.4
114	41.7	75.1	.3498	1.3683	1.068	17.10	.936	.0585	237.2
115	41.8	75.3	.3524	1.3631	1.036	16.59	.965	.0603	239.0
116	41.9	75.4	.3550	1.3579	1.005	16.09	.995	.0622	240.8
117	42.0	75.6	.3576	1.3527	0.9746	15.61	1.026	.0641	242.6
118	42.1	75.8	.3602	1.3475	0.9460	15.16	1.057	.0659	244.4
119	42.2	75.9	.3628	1.3423	0.9183	14.72	1.089	.0679	246.2

TABLE 290 (*continued*)

PROPERTIES OF SATURATED STEAM

Metric and Common Units 0° to 220° C

Temperature Degrees Centigrade.	Pressure			Heat of the Liquid.		Heat of Vaporization.		Heat Equivalent of Internal Work.		Temperature Degrees Fahrenheit.
	Mm of Mercury	Kg per sq. cm	Pds. per sq. in.	Calories.	B. T. U.	Calories.	B. T. U.	Calories	B. T. U.	
t.	p.	p.	p.	q.	q.	r.	r	ρ	ρ.	t.
120	1489	2.024	28.79	120.4	216.7	525.6	946.0	483.4	870.0	248.0
121	1537	2.089	29.72	121.4	218.5	524.9	944.8	482.6	868.6	249.8
122	1586	2.156	30.66	122.5	220.4	524.2	943.5	481.8	867.1	251.6
123	1636	2.224	31.64	123.5	222.2	523.5	942.3	481.0	865.8	253.4
124	1688	2.294	32.64	124.5	224.1	522.8	941.0	480.2	864.3	255.2
125	1740	2.366	33.66	125.5	225.9	522.1	939.9	479.4	863.0	257.0
126	1795	2.440	34.71	126.5	227.7	521.4	938.6	478.6	861.6	258.8
127	1850	2.516	35.78	127.5	229.5	520.7	937.3	477.8	860.2	260.6
128	1907	2.593	36.88	128.6	231.4	520.0	936.1	477.0	858.8	262.4
129	1966	2.673	38.01	129.6	233.3	519.3	934.8	476.3	857.4	264.2
130	2026	2.754	39.17	130.6	235.1	518.6	933.6	475.5	856.0	266.0
131	2087	2.837	40.36	131.6	236.9	517.9	932.3	474.7	854.6	267.8
132	2150	2.923	41.57	132.6	238.7	517.3	931.1	474.0	853.2	269.6
133	2214	3.010	42.81	133.7	240.6	516.6	929.8	473.3	851.8	271.4
134	2280	3.100	44.09	134.7	242.4	515.9	928.5	472.5	850.4	273.2
135	2348	3.192	45.39	135.7	244.2	515.1	927.2	471.6	848.9	275.0
136	2416	3.285	46.73	136.7	246.0	514.4	925.9	470.8	847.5	276.8
137	2487	3.382	48.10	137.7	247.9	513.7	924.6	470.1	846.1	278.6
138	2560	3.480	49.50	138.8	249.7	513.0	923.3	469.3	844.6	280.4
139	2634	3.581	50.93	139.8	251.6	512.3	922.1	468.5	843.3	282.2
140	2710	3.684	52.39	140.8	253.4	511.5	920.7	467.6	841.8	284.0
141	2787	3.789	53.89	141.8	255.3	510.7	919.3	466.8	840.2	285.8
142	2866	3.897	55.43	142.8	257.1	510.1	918.1	466.1	838.9	287 6
143	2948	4.008	57.00	143.9	259.0	509.3	916.7	465.3	837.4	289.4
144	3030	4.121	58.60	144.9	260.8	508.6	915.4	464.4	835.9	291.2
145	3115	4.236	60.24	145.9	262.7	507.8	914.1	463.6	834.5	293.0
146	3202	4.354	61.92	146.9	264.5	507.1	912.8	462.8	833.1	294.8
147	3291	4.474	63.64	148.0	266.4	506.4	911.5	462.0	831.6	296.6
148	3381	4.597	65.39	149.0	268.2	505.6	910.1	461.2	830.1	298.4
149	3474	4.723	67.18	150.0	270.1	504.9	908.8	460.4	828.7	300.2
150	3569	4.852	69.01	151.0	271.9	504.1	907.4	459.5	827.2	302.0
151	3665	4.984	70.88	152.1	273.8	503.4	906.1	458.7	825.7	303.8
152	3764	5.118	72.79	153.1	275.6	502.6	904.7	457.9	824.2	305.6
153	3865	5.255	74.74	154.1	277.4	501.9	903.3	457.1	822.7	307.4
154	3968	5.395	76.73	155.1	279.2	501.1	901.9	456.3	821.2	309.2
155	4073	5.538	78.76	156.2	281.1	500.3	900.5	455.4	819.6	311.0
156	4181	5.684	80.84	157.2	283.0	499.6	899.2	454.6	818.2	312.8
157	4290	5.833	82.96	158.2	284.8	498.8	897.8	453.8	816.7	314.6
158	4402	5.985	85.12	159.3	286.7	498.1	896.5	453.0	815.3	316.4
159	4517	6.141	87.33	160.3	288.5	497.3	895.1	452.1	813.7	318.2
160	4633	6.300	89.59	161.3	290.4	496.5	893.7	451.2	812.2	320.0
161	4752	6.462	91.89	162.3	292.2	495.7	892.3	450.4	810.7	321.8
162	4874	6.628	94.25	163.4	294.1	494.9	890.9	449.5	809.2	323.6
163	4998	6.796	96.65	164.4	295.9	494.2	889.5	448.7	807.7	325.4
164	5124	6.967	99.09	165.4	297.7	493.4	888.1	447.9	806.2	327.2
165	5253	7.142	101.6	166.5	299.6	492.6	886.7	447.0	804.7	329.0
166	5384	7.320	104.1	167.5	301.5	491.9	885.4	446.3	803.3	330.8
167	5518	7.502	106.7	168.5	303.3	491.1	883.9	445.4	801.7	332.6
168	5655	7.688	109.4	169.5	305.1	490.3	882.5	444.6	800.1	334.4
169	5794	7.877	112.0	170.6	307.0	489.5	881.0	443.7	798.5	336.2

PROPERTIES OF SATURATED STEAM

Metric and Common Units 0° to 220° C

Temperature Degrees Centigrade. t.	Heat Equivalent of External Work. Calories. Apu.	B. T. U. Apu.	Entropy of the Liquid. θ	Entropy of Evaporation. $\frac{r}{T}$	Specific Volume. Cubic Meters per Kilogram. s	Cubic Feet per Pound. s	Density. Kilograms per Cubic Meter. $\frac{1}{s}$	Pounds per Cubic Foot. $\frac{1}{s}$	Temperature Degrees Fahrenheit. t.
120	42.2	76.0	0.3654	1.3372	0.8914	14.28	1.122	0.0700	248.0
121	42.3	76.2	.3680	1.3321	.8653	13.86	1.156	.0721	249.8
122	42.4	76.4	3705	1.3269	.8401	13.46	1.190	.0743	251.6
123	42.5	76.5	.3731	1.3218	.8158	13.07	1.226	.0765	253.4
124	42.6	76.7	.3756	1.3167	.7924	12.69	1.262	.0788	255.2
125	42.7	76.8	.3782	1.3117	.7698	12.33	1.299	.0811	257.0
126	42.8	77.0	.3807	1.3067	.7479	11.98	1.337	.0835	258.8
127	42.9	77.1	.3833	1.3017	.7267	11.64	1.376	.0859	260.6
128	43.0	77.3	.3858	1.2967	.7063	11.32	1.416	.0883	262.4
129	43.0	77.4	.3884	1.2917	.6867	11.00	1.456	.0909	264.2
130	43.1	77.6	.3909	1.2868	.6677	10.70	1.498	.0935	266.0
131	43.2	77.7	.3934	1.2818	.6493	10.40	1.540	.0961	267.8
132	43.3	77.9	.3959	1.2769	.6315	10.12	1.583	.0988	269.6
133	43.3	78.0	.3985	1.2720	.6142	9.839	1.628	.1016	271.4
134	43.4	78.1	.4010	1.2672	.5974	9.569	1.674	.1045	273.2
135	43.5	78.3	.4035	1.2623	.5812	9.309	1.721	.1074	275.0
136	43.6	78.4	.4060	1.2574	.5656	9.060	1.768	.1104	276.8
137	43.6	78.5	.4085	1.2526	.5506	8.820	1.816	.1134	278.6
138	43.7	78.7	.4110	1.2479	.5361	8.587	1.865	.1165	280.4
139	43.8	78.8	.4135	1.2431	.5219	8.360	1.916	.1196	282.2
140	43.9	78.9	.4160	1.2383	.5081	8.140	1.968	.1229	284.0
141	43.9	79.1	.4185	1.2335	.4948	7.926	2.021	.1262	285.8
142	44.0	79.2	.4209	1.2288	.4819	7.719	2.075	.1296	287.6
143	44.0	79.3	.4234	1.2241	.4694	7.519	2.130	.1330	289.4
144	44.2	79.5	.4259	1.2194	.4574	7.326	2.186	.1365	291.2
145	44.2	79.6	.4283	1.2147	.4457	7.139	2.244	.1401	293.0
146	44.3	79.7	.4307	1.2100	.4343	6.957	2.303	.1437	294.8
147	44.4	79.9	.4332	1.2054	.4232	6.780	2.363	.1475	296.6
148	44.4	80.0	.4356	1.2008	.4125	6.609	2.424	.1513	298.4
149	44.5	80.1	.4380	1.1962	.4022	6.443	2.486	.1552	300.2
150	44.6	80.2	.4405	1.1916	.3921	6.282	2.550	.1592	302.0
151	44.6	80.4	.4429	1.1870	.3824	6.126	2.615	.1632	303.8
152	44.7	80.5	.4453	1.1824	.3729	5.974	2.682	.1674	305.6
153	44.8	80.6	.4477	1.1778	.3637	5.826	2.750	.1716	307.4
154	44.8	80.7	.4501	1.1733	.3548	5.683	2.818	.1759	309.2
155	44.9	80.9	.4525	1.1688	.3463	5.546	2.888	.1803	311.0
156	45.0	81.0	.4549	1.1644	.3380	5.413	2.959	.1847	312.8
157	45.0	81.1	.4573	1.1599	.3298	5.282	3.032	.1893	314.6
158	45.1	81.2	.4596	1.1554	.3218	5.154	3.108	.1940	316.4
159	45.2	81.4	.4620	1.1509	.3140	5.029	3.185	.1988	318.2
160	45.3	81.5	.4644	1.1465	.3063	4.906	3.265	.2038	320.0
161	45.3	81.6	.4668	1.1421	.2989	4.789	3.345	.2088	321.8
162	45.4	81.7	.4692	1.1377	.2920	4.677	3.425	.2138	323.6
163	45.5	81.8	.4715	1.1333	.2855	4.571	3.503	.2188	325.4
164	45.5	81.9	.4739	1.1289	.2792	4.469	3.582	.2238	327.2
165	45.6	82.0	.4763	1.1245	.2729	4.368	3.664	.2289	329.0
166	45.6	82.1	.4786	1.1202	.2666	4.268	3.751	.2343	330.8
167	45.7	82.2	.4810	1.1159	.2603	4.168	3.842	.2399	332.6
168	45.7	82.4	.4833	1.1115	.2540	4.070	3.937	.2457	334.4
169	45.8	82.5	.4857	1.1072	.2480	3.975	4.032	.2516	336.2

Table 290 (*continued*)

PROPERTIES OF SATURATED STEAM

Metric and Common Units 0° to 220° C

Temperature Degrees Centigrade.	Pressure.			Heat of the Liquid.		Heat of Vaporization.		Heat Equivalent of Internal Work.		Temperature Degrees Fahrenheit.
	Mm of Mercury.	Kg per sq. cm	Pds. per sq in.	Calories.	B. T. U	Calories.	B. T. U.	Calories.	B. T. U.	
t.	p	p.	p.	q.	q.	r.	r.	ρ.	ρ.	t.
170	5937	8.071	114 8	171.6	308.9	488.7	879.6	442.8	797.0	338.0
171	6081	8.268	117.6	172.6	310.7	487.9	878.3	441.9	795.6	339.8
172	6229	8.469	120 4	173.7	312.6	487.1	876.9	441.1	794.1	341.6
173	6379	8.673	123.4	174.7	314.5	486.3	875.4	440.2	792.5	343.4
174	6533	8.882	126.3	175.7	316.3	485.5	873.9	439.4	790.9	345.2
175	6689	9.094	129.4	176.8	318.2	484.7	872.4	438.5	789.3	347.0
176	6848	9.310	132.4	177.8	320.0	483.9	871.0	437.7	787.8	348.8
177	7010	9.531	135.6	178.8	321.8	483.1	869.5	436.8	786.2	350.6
178	7175	9.755	138.8	179.9	323.7	482.3	868.1	436.0	784.7	352.4
179	7343	9.983	142.0	180.9	325.6	481.4	866.6	435.0	783.1	354.2
180	7514	10.216	145.3	181.9	327.5	480.6	865.1	434.2	781.5	356.0
181	7688	10.453	148.7	183.0	329.3	479.8	863.6	433.3	779.9	357.8
182	7866	10.695	152.1	184.0	331.2	479.0	862.2	432.5	778.4	359.6
183	8046	10.940	155.6	185.0	333.0	478.2	860.7	431.6	776.9	361.4
184	8230	11.189	159.2	186.1	334.9	477.4	859.2	430.8	775.3	363.2
185	8417	11.44	162.8	187.1	336.8	476.6	857.7	429.9	773.7	365.0
186	8608	11.70	166.5	188.1	338.6	475 7	856.3	429.0	772.2	366.8
187	8802	11.97	170.2	189.2	340.5	474.8	854.7	428.0	770.5	368.6
188	8999	12.24	174.0	190.2	342.4	474.0	853.2	427.2	768.9	370.4
189	9200	12.51	177.9	191.2	344.2	473.2	851.7	426.3	767.4	372.2
190	9404	12.79	181.8	192.3	346.1	472.3	850.2	425.4	765.8	374.0
191	9612	13.07	185.9	193.3	347.9	471.5	848.7	424.5	764.2	375.8
192	9823	13.36	190.0	194.4	349.8	470.6	847.1	423.6	762.5	377.6
193	10038	13.65	194.1	195.4	351.7	469.8	845.6	422.8	761.0	379.4
194	10256	13.94	198.3	196.4	353.5	468.9	844.1	421.9	759.4	381.2
195	10480	14.25	202.6	197.5	355.4	468.1	842.5	421.0	757.7	383.0
196	10700	14.55	207.0	198.5	357.3	467.2	841.0	420.1	756.1	384.8
197	10930	14.87	211.4	199.5	359.2	466.4	839.5	419.2	754.6	386.6
198	11170	15.18	216.0	200.6	361.1	465.6	838.0	418.4	753.0	388.4
199	11410	15.51	220.6	201.6	362.9	464.7	836.4	417.4	751.3	390.2
200	11650	15.84	225.2	202.7	364.8	463.8	834.8	416.5	749.7	392.0
201	11890	16.17	223.0	203.7	366.7	462.9	833.3	415.6	748.1	393.8
202	12140	16.51	234.8	204.7	368.5	462.1	831.8	414.8	746.6	395.6
203	12400	16.85	239.7	205.8	370.4	461.2	830.2	413.8	744.9	397.4
204	12650	17.20	244.7	206.8	372.3	460.3	828.6	412.9	743.3	399.2
205	12920	17.56	249.8	207.9	374.1	459.4	827.0	412.0	741.6	401.0
206	13180	17.92	254.9	208.9	376.0	458.6	825.4	411.1	740.0	402.8
207	13450	18.29	260.1	210.0	377.9	457.7	823.8	410.2	738.3	404.6
208	13730	18.66	265.4	211.0	379.8	456.8	822.2	409.3	736.7	406.4
209	14010	19.04	270.8	212.0	381.6	455.9	820.6	408.4	735.1	408.2
210	14290	19.43	276.3	213.1	383.5	455.0	819.1	407.5	733.6	410.0
211	14580	19.82	281.9	214.1	385.4	454.1	817.4	406.6	731.9	411.8
212	14870	20.22	287.6	215.2	387.3	453.2	815.8	405.7	730.2	413.6
213	15170	20.62	293.3	216.2	389.2	452.4	814.3	404.9	728.7	415.4
214	15470	21.03	299.2	217.3	391.1	451.5	812.7	404.0	727.1	417.2
215	15780	21.45	305.1	218.3	392.9	450.6	811.0	403.1	725.4	419.0
216	16090	21.88	311.1	219.3	394.8	449.6	809.3	402.1	723.7	420.8
217	16410	22.31	317.3	220.4	396.7	448.7	807.7	401.2	722.1	422.6
218	16730	22.74	323.5	221.4	398.5	447.8	806.1	400.3	720.5	424.4
219	17060	23.19	329.8	222.5	400.4	446.9	804.5	399.4	718.9	426 2
220	17390	23.64	336.2	223 5	402.3	446.0	802.9	398.5	717.3	428.0

PROPERTIES OF SATURATED STEAM

Metric and Common Units 0° to 220° C

Temperature Degrees Centigrade.	Heat Equivalent of External Work.		Entropy of the Liquid.	Entropy of Evaporation.	Specific Volume.		Density.		Temperature Degrees Fahrenheit.
	Calories.	B. T. U.			Cubic Meters per Kilogram.	Cubic Feet per Pound.	Kilograms per Cubic Meter.	Pounds per Cubic Foot.	
t.	Apu.	Apu.	θ	$\frac{r}{T}$	s	s	$\frac{1}{s}$	$\frac{1}{s}$	t.
170	45.9	82.6	0.4880	1.1029	0.2423	3.883	4.127	0.2575	338.0
171	46.0	82.7	.4903	1.0987	.2368	3.794	4.223	.2636	339.8
172	46.0	82.8	.4926	1.0944	.2314	3.709	4.322	.2696	341.6
173	46.1	82.9	.4949	1.0901	.2262	3.626	4.421	.2758	343.4
174	46.1	83.0	.4972	1.0859	.2212	3.545	4.521	.2821	345.2
175	46.2	83.1	.4995	1.0817	.2164	3.467	4.621	.2884	347.0
176	46.2	83.2	.5018	1.0775	.2117	3.391	4.724	.2949	348.8
177	46.3	83.3	.5041	1.0733	.2072	3.318	4.826	.3014	350.6
178	46.3	83.4	.5064	1.0691	.2027	3.247	4.933	.3080	352.4
179	46.4	83.5	.5087	1.0649	.1983	3.177	5.04	.3148	354.2
180	46.4	83.6	.5110	1.0608	.1941	3.109	5.15	.3217	356.0
181	46.5	83.7	.5133	1.0567	.1899	3.041	5.27	.3288	357.8
182	46.5	83.8	.5156	1.0525	.1857	2.974	5.38	.3362	359.6
183	46.6	83.8	.5178	1.0484	.1817	2.911	5.50	.3435	361.4
184	46.6	83.9	.5201	1.0443	.1778	2.849	5.62	.3510	363.2
185	46.7	84.0	.5224	1.0403	.1740	2.787	5.75	.3588	365.0
186	46.7	84.1	.5246	1.0362	.1702	2.727	5.88	.3667	366.8
187	46.8	84.2	.5269	1.0321	.1666	2.669	6.00	.3746	368.6
188	46.8	84.3	.5291	1.0280	.1632	2.614	6.13	.3826	370.4
189	46.9	84.3	.5314	1.0240	.1598	2.560	6.26	.3906	372.2
190	46.9	84.4	.5336	1.0200	.1565	2.507	6.39	.3989	374.0
191	47.0	84.5	.5358	1.0160	.1533	2.456	6.52	.4072	375.8
192	47.0	84.6	.5381	1.0120	.1501	2.405	6.66	.4158	377.6
193	47.0	84.6	.5403	1.0080	.1470	2.355	6.80	.4246	379.4
194	47.0	84.7	.5426	1.0040	.1440	2.306	6.94	.4336	381.2
195	47.1	84.8	.5448	1.0000	.1411	2.259	7.09	.4426	383.0
196	47.1	84.9	.5470	0.9961	.1382	2.214	7.23	.4516	384.8
197	47.2	84.9	.5492	.9922	.1354	2.169	7.38	.4610	386.6
198	47.2	85.0	.5514	.9882	.1327	2.126	7.53	.4704	388.4
199	47.3	85.1	.5536	.9843	.1300	2.083	7.69	.4801	390.2
200	47.3	85.1	.5558	.9804	.1274	2.041	7.84	.4900	392.0
201	47.3	85.2	.5580	.9765	.1249	2.001	8.00	.4998	393.8
202	47.3	85.2	.5602	.9727	.1225	1.962	8.16	.510	395.6
203	47.4	85.3	.5624	.9688	.1201	1.923	8.33	.520	397.4
204	47.4	85.3	.5646	.9650	.1177	1.885	8.50	.531	399.2
205	47.4	85.4	.5668	.9611	.1153	1.847	8.67	.541	401.0
206	47.5	85.4	.5690	.9572	.1130	1.810	8.85	.552	402.8
207	47.5	85.5	.5712	.9534	.1108	1.774	9.03	.564	404.6
208	47.5	85.5	.5733	.9496	.1086	1.739	9.21	.575	406.4
209	47.5	85.5	.5755	.9458	.1065	1.705	9.39	.587	408.2
210	47.5	85.5	.5777	.9420	.1044	1.673	9.58	.598	410.0
211	47.5	85.5	.5799	.9382	.1024	1.640	9.77	.610	411.8
212	47.5	85.6	.5820	.9344	.1004	1.608	9.96	.622	413.6
213	47.5	85.6	.5842	.9307	.0984	1.577	10.16	.634	415.4
214	47.5	85.6	.5863	.9269	.0965	1.546	10.36	.647	417.2
215	47.5	85.6	.5885	.9232	.0947	1.516	10.56	.660	419.0
216	47.5	85.6	.5906	.9195	.0928	1.486	10.78	.673	420.8
217	47.5	85.6	.5927	.9157	.0910	1.458	10.99	.686	422.6
218	47.5	85.6	.5948	.9120	.0893	1.430	11.20	.699	424.4
219	47.5	85.6	.5969	.9084	.0876	1.403	11.41	.713	426.2
220	47.5	85.6	.5991	.9047	.0860	1.376	11.62	.727	428.0

Table 291

PROPERTIES OF SATURATED STEAM

Common Units, 400° to 700° F.

Abridged from Steam Tables and Mollier's Diagram by Keenan. Printed by permission of the publisher, The American Society of Mechanical Engineers. For detailed discussion see Mechanical Engineering, Feb., 1929. v, specific vol., ft.³/lb.; h, total heat, enthalpy, B.t.u./lb.; s, entropy, B.t.u./°F./lb. The strict definition of total heat (internal energy + $144/J$) is adhered to; zeros of both h and s are arbitrarily placed on the sat. liq. line at 32°F. No internal energy values are tabulated but may be easily found by subtracting $144\ pv/J$ from the total heat. The energy unit, the B.t.u., is 778.57 ft.-lb. (J) is 1/180 of the change in total heat along the saturated liquid line between 32° and 212°F. (Osborne, Fiock, Stimson.)

Temp. F.	Abs. p.	Specific Volume			Total Heat			Entropy		
		Sat. liq.	Evap.	Sat. vapor	Sat. liq.	Evap.	Sat. vap.	Sat. liq.	Evap.	Sat. vapor
t	lb./in.²	v_f	v_{fg}	v_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
400	247.25	0.01865	1.8421	1.8608	375.0	826	1200	0.5668	0.9602	1.5270
405	261.67	.01873	1.7428	1.7615	380.4	821	1201	.5730	.9491	1.5221
410	276.72	.01880	1.6493	1.6681	385.9	816	1202	.5792	.9381	1.5173
415	292.44	.01888	1.5615	1.5804	391.3	811	1202	.5854	.9271	1.5125
420	308.82	.01896	1.4792	1.4982	396.8	806	1203	.5916	.9161	1.5077
425	325.91	.01904	1.4022	1.4212	402.4	801	1203	.5978	.9052	1.5029
430	343.71	.01911	1.3295	1.3486	407.9	796	1203	.6039	.8942	1.4982
435	362.27	.01919	1.2610	1.2802	413.5	790	1204	.6101	.8833	1.4934
440	381.59	.01928	1.1965	1.2158	419.1	785	1204	.6162	.8724	1.4887
445	401.70	.01936	1.1356	1.1550	424.7	779	1204	.6224	.8616	1.4839
450	422.61	.0195	1.0782	1.0977	430	774	1204	.6284	.8507	1.4792
455	444.35	.0195	1.0241	1.0436	436	768	1204	.6346	.8398	1.4744
460	466.94	.0196	.9730	.9927	442	762	1204	.6407	.8290	1.4696
465	490.40	.0197	.9249	.9446	447	756	1204	.6468	.8180	1.4649
470	514.76	.0198	.8793	.8991	453	750	1204	.6530	.8071	1.4601
475	540.04	.0199	.8361	.8560	459	744	1203	.6592	.7962	1.4554
480	566.26	.0200	.7951	.8151	465	738	1203	.6654	.7852	1.4506
485	593.47	.0201	.7563	.7764	471	731	1202	.6716	.7742	1.4458
490	621.67	.0202	.7195	.7398	477	725	1202	.6779	.7632	1.4410
495	650.87	.0204	.6847	.7050	483	718	1201	.6842	.7521	1.4362
500	681.09	.0205	.6516	.6721	489	711	1200	.6904	.7410	1.4314
505	712.40	.0206	.6201	.6408	495	704	1199	.6968	.7299	1.4266
510	744.74	.0207	.5903	.6110	502	697	1198	.7031	.7187	1.4218
515	778.16	.0209	.5618	.5826	508	690	1197	.7094	.7075	1.4170
520	812.72	.0210	.5347	.5557	514	682	1196	.7158	.6963	1.4121
525	848.43	.0211	.5090	.5301	521	675	1195	.7222	.6851	1.4073
530	885.31	.0213	.4845	.5058	527	667	1193	.7286	.6738	1.4024
535	923.39	.0214	.4614	.4828	533	659	1192	.7350	.6625	1.3975
540	962.73	.0216	.4394	.4610	540	651	1191	.7414	.6512	1.3926
545	1003.4	.0218	.4184	.4401	547	643	1189	.7478	.6399	1.3877
550	1045.4	.0219	.3982	.4201	553	634	1188	.7543	.6285	1.3828
555	1088.7	.0221	.3789	.4010	560	626	1186	.7607	.6170	1.3778
560	1133.4	.0223	.3605	.3828	567	618	1184	.7672	.6056	1.3728
565	1179.7	.0225	.3429	.3654	574	609	1182	.7737	.5940	1.3677
570	1227.6	.0227	.3261	.3488	580	600	1180	.7802	.5825	1.3626
575	1276.7	.0229	.3101	.3330	587	591	1178	.7867	.5709	1.3576
580	1327.2	.0231	.2949	.3180	594	581	1176	.7932	.5592	1.3524
585	1379.2	.0234	.2804	.3037	602	572	1173	.7998	.5474	1.3472
590	1432.7	.0236	.2664	.2900	609	562	1171	.8064	.5356	1.3420
595	1487.8	.0239	.2530	.2769	616	552	1168	.8131	.5237	1.3368
600	1544.6	.0241	.2401	.2642	623	542	1166	.8198	.5118	1.3316
610	1663.2	.0247	.2159	.2406	638	521	1160	.8332	.4875	1.3208
620	1788.8	.0254	.1933	.2186	653	499	1153	.8470	.4623	1.3093
630	1921.9	.0261	.1721	.1982	670	475	1144	.8612	.4358	1.2970
640	2062.8	.0269	.1522	.1791	687	448	1135	.8763	.4073	1.2836
650	2211.4	.0278	.1331	.1610	705	417	1122	.8924	.3764	1.2688
660	2368.6	.0290	.1148	.1437	725	384	1109	.9097	.3426	1.2523
670	2534.2	.0304	.0966	.1269	748	344	1092	.9287	.3049	1.2336
680	2709.7	.0322	.0781	.1102	773	299	1071	.9499	.2619	1.2119
690	2896.8	.0347	.0589	.0936	803	241	1044	.9755	.2098	1.1852
700	3096.4	.0394	.0353	.0747	846	157	1003	1.0117	.1354	1.1471
705	3202.0	.0462	.0135	.0597	888	73	962	1.0472	.0630	1.1102
706.1	3226.0	.0522	0	.0522	925	0	925	1.0785	0	1.0785

Table 292

PROPERTIES OF SUPERHEATED STEAM

Common Units, 212° to 3000°F.

(Abridged from Steam Tables and Mollier's Diagram by Keenan, 1930. Printed by permission of publisher, The American Society of Mechanical Engineers.)

Abs. P. lb./in.² (Sat. t. F.)	Sat. water	Sat. steam	200°F.	300°F.	400°F.	500°F.	600°F.	700°F.	800°F.	900°F.	1000°F.
	0.02	26.82	27.16	30.52	34.65	38.75	42.83	46.91	50.97	55.03	59.09
14.696	180.0	1150.2	1154.	1192.	1239.	1286.	1334.	1382.	1432.	1483.	1535.
(212.00)	0.3119	1.7564	1.762	1.815	1.873	1.925	1.972	2.016	2.057	2.096	2.133
	0.017	8.514	v	8.78	10.06	11.30	12.53	13.74	14.93	16.14	17.34
50	250.0	1173.5	h	1184.	1234.	1283.	1331.	1381.	1431.	1482.	1534.
(281.01)	0.4111	1.6580	s	1.672	1.734	1.787	1.836	1.880	1.922	1.961	1.998
	0.018	4.426	v	.....	4.93	5.58	6.21	6.83	7.44	8.04	8.64
100	298.3	1186.6	h	.....	1227.	1278.	1328.	1378.	1429.	1481.	1533.
(327.83)	0.4742	1.6022	s	.....	1.651	1.708	1.757	1.802	1.844	1.884	1.921
	0.018	3.010	v	.....	3.22	3.68	4.11	4.53	4.94	5.34	5.75
150	330.4	1194.	h	.....	1219.	1273.	1324.	1376.	1427.	1479.	1532.
(358.43)	0.5140	1.569	s	.....	1.599	1.659	1.710	1.756	1.799	1.838	1.876
	0.018	2.285	v	.....	2.358	2.722	3.06	3.38	3.69	4.00	4.30
200	355.	1198.	h	.....	1210.	1268.	1321.	1373.	1426.	1478.	1531.
(381.82)	0.543	1.545	s	.....	1.559	1.623	1.676	1.723	1.766	1.806	1.8438
	0.0189	1.541	v	.....	.....	1.765	2.002	2.224	2.438	2.646	2.849
300	394.	1202.	h	.....	.....	1257.	1313.	1368.	1422.	1475.	1529.
(417.33)	0.5883	1.510	s	.....	.....	1.569	1.626	1.675	1.719	1.760	1.798
	0.0194	1.160	v	.....	.....	1.283	1.474	1.647	1.812	1.970	2.125
400	424.	1204.	h	.....	.....	1244.	1306.	1362.	1418.	1472.	1527.
(444.58)	0.622	1.484	s	.....	.....	1.528	1.588	1.640	1.685	1.727	1.766
	0.0198	0.926	v = sp. vol.			0.991	1.156	1.301	1.436	1.566	1.690
500	450.	1204.	h = total heat			1230.	1297.	1357.	1414.	1469.	1525.
	0.649	1.463	s = entropy			1.491	1.558	1.611	1.659	1.701	1.740

Abs. P. lb./in.² (Sat. t. F.)	Sat. water	Sat. steam	500°F.	550°F.	600°F.	650°F.	700°F.	750°F.	800°F.	850°F.	900°F.	950°F.	1000°F.
	0.0202	0.768	0.792	0.873	0.943	1.008	1.069	.....	1.186	v	1.295	.....	1.400
600	472.	1202.	1215.	1255.	1289.	1320.	1351.	.....	1409.	h	1466.	.....	1523.
(486.17)	0.673	1.445	1.458	1.499	1.532	1.561	1.587	.....	1.636	s	1.679	.....	1.720
	0.0206	0.653	v	0.725	0.791	0.849	0.904	.....	1.006	.....	1.103	.....	1.193
700	493.	1200.	h	1242.	1280.	1313.	1345.	.....	1405.	.....	1463.	.....	1521.
(503.04)	0.694	1.429	s	1.472	1.508	1.539	1.567	.....	1.617	.....	1.661	.....	1.702
	0.0209	0.565	v	0.613	0.675	0.729	0.779	.....	0.872	0.916	0.958	0.998	1.037
800	512.	1197.	h	1229.	1270.	1305.	1338.	.....	1400.	1430.	1460.	1489.	1519.
(518.18)	0.714	1.414	s	1.446	1.486	1.519	1.548	.....	1.599	1.623	1.645	1.666	1.686
	0.0213	0.497	v	0.523	0.584	0.636	0.682	.....	0.768	0.807	0.845	0.882	0.917
900	530.	1193.	h	1214.	1260.	1297.	1332.	.....	1396.	1427.	1457.	1487.	1517.
(531.95)	0.731	1.401	s	1.421	1.466	1.500	1.530	.....	1.583	1.607	1.630	1.652	1.672
	0.0217	0.442	v	0.450	0.511	0.560	0.604	0.645	0.684	0.720	0.755	0.788	0.820
1000	546.	1190.	h	1197.	1249.	1289.	1325.	1358.	1391.	1423.	1454.	1484.	1515.
(544.58)	0.747	1.388	s	1.395	1.446	1.483	1.514	1.538	1.569	1.593	1.617	1.639	1.660
	0.0239	0.274	..	v	0.279	0.330	0.368	0.401	0.432	0.459	0.484	0.508	0.530
1500	618.	1168.	..	h	1174.	1240.	1287.	1327.	1365.	1402.	1438.	1472.	1505.
(596.08)	0.815	1.336	..	s	1.342	1.403	1.444	1.478	1.509	1.537	1.564	1.589	1.612
	0.0265	0.188	..	..	v	0.204	0.247	0.278	0.305	0.327	0.349	0.367	0.384
2000	679.	1139.	..	..	h	1169.	1241.	1291.	1337.	1380.	1421.	1459.	1495.
(635.61)	0.870	1.290	..	..	s	1.317	1.380	1.423	1.460	1.493	1.524	1.552	1.577
	0.0301	0.130	..	..	..	v	0.168	0.202	0.227	0.248	0.267	0.282	0.298
2500	743.	1096.	..	..	..	h	1178.	1250.	1306.	1357.	1404.	1446.	1484.
(667.98)	0.925	1.238	..	..	..	s	1.310	1.371	1.416	1.456	1.491	1.521	1.548
	0.0367	0.084	..	..	..	v	.0983	.1476	.1742	.1947	0.212	0.227	0.240
3000	823.	1026.	..	..	..	h	1066.	1199.	1271.	1331.	1384.	1432.	1473.
(695.25)	0.992	1.168	..	..	..	s	1.203	1.316	1.374	1.420	1.460	1.494	1.523

TABLE 293.—Properties of Mercury Vapor

402° to 1000° F.

Pressure abs. lbs./in.²	Temperature °F.	Heat of liquid above 32° F. B.t.u.	Heat of vaporization B.t.u.	Total heat B.t.u.	Entropy of liquid above 32° F.	Entropy of vaporization	Total entropy	Specific volume cu. ft./lb.	Weight lbs./cu. ft.
0.4	402	13.81	128.15	141.96	.0209	.1487	.1696	114.50	0.008733
0.8	444	15.36	127.24	142.60	.0227	.1408	.1635	59.72	.016745
1.0	458	15.89	126.92	142.81	.0233	.1383	.1616	48.45	.02064
1.5	485	16.90	126.33	143.23	.0244	.1337	.1581	33.14	.03017
2.0	505	17.65	125.89	143.54	.0251	.1305	.1556	25.32	.03948
4.0	558	19.62	124.72	144.34	.0271	.1226	.1497	13.26	.07540
6.0	591	20.87	123.99	144.86	.0283	.1179	.1462	9.096	.10093
8.0	617	21.81	123.43	145.24	.0292	.1147	.1439	6.9630	.14361
10.0	637	22.58	122.98	145.56	.0299	.1121	.1420	5.6610	.17664
15.0	676	24.04	122.12	146.16	.0312	.1075	.1387	3.8923	.25691
20.0	706	25.15	121.46	146.61	.0322	.1042	.1364	2.983	.3352
25.0	730	26.05	120.93	146.98	.0330	.1016	.1346	2.429	.4117
30.0	751	26.81	120.48	147.29	.0336	.0995	.1331	2.053	.4871
35.0	769	27.49	120.08	147.57	.0342	.0977	.1319	1.7815	.5613
40.0	785	28.08	119.73	147.81	.0346	.0962	.1308	1.5762	.6344
45.0	799	28.62	119.42	148.04	.0351	.0949	.1300	1.4147	.7069
50	812	29.11	119.13	148.24	.0355	.0936	.1291	1.284	.7788
60	836	29.99	118.61	148.60	.0361	.0915	.1276	1.086	.9204
70	857	30.75	118.15	148.90	.0367	.0898	.1265	.9436	1.0597
80	875	31.44	117.75	149.19	.0372	.0882	.1254	.8349	1.1977
90	892	32.06	117.38	149.44	.0377	.0870	.1247	.7497	1.3338
100	907	32.63	117.05	149.68	.0381	.0856	.1237	.6811	1.4682
110	921	33.16	116.74	149.90	.0385	.0845	.1230	.6242	1.6020
120	934	33.66	116.44	150.10	.0389	.0835	.1224	.5767	1.7340
130	947	34.12	116.17	150.29	.0392	.0826	.1218	.5360	1.8656
140	958	34.55	115.92	150.47	.0395	.0818	.1213	.5012	1.9952
150	960	34.96	115.67	150.63	.0398	.0809	.1207	.4706	2.125
180	1000	36.09	115.01	151.10	.0406	.0788	.1194	.3990	2.506

(Adapted from Emmet Mercury Vapor Process, Emmet and Sheldon, Amer. Soc. Mech. Eng., May, 1924.)

TABLE 294.—Properties of Liquid Ammonia

−100° to +250°F.

Temp. °F. t	Saturation: Pressure (abs.) lbs./in.² p	Volume ft.³/lb. v	Density lbs./ft.³ $\frac{1}{v}$	Specific heat B.t.u./lb. °F. c	Heat content B.t.u./lb. h	Latent heat B.t.u./lb. L	Latent heat of pressure variation $\frac{\text{B.t.u./lb.}}{\text{lb./in.}^2}$ l	Variation of h with p t constant $\frac{\text{B.t.u./lb.}}{\text{lb./in.}^2}$ $\left(\frac{\partial h}{\partial p}\right)_t$	Compressibility per lb./in.²×10⁶ $-\frac{1}{v}\left(\frac{\partial v}{\partial p}\right)_t$
−100	1.24	.02197	45.52	(1.040)	(−63.0)	(633)			
− 90	1.86	.02216	45.12	(1.043)	(−52.6)	(628)			
−80	2.74	.02236	44.72	(1.046)	(−42.2)	(622)			
−70	3.94	.02256	44.32	(1.050)	(−31.7)	(616)			
−60	5.55	.02278	43.91	1.054	−21.18	610.8	−.0016	.0026	4.4
−50	7.67	.02299	43.49	1.058	−10.61	604.3	−.0017	.0026	4.6
−40	10.41	.02322	43.08	1.062	0.00	597.6	−.0018	.0025	4.8
−30	13.90	.02345	42.65	1.066	+10.66	590.7	−.0019	.0025	5.1
−20	18.30	.02369	42.22	1.070	+21.36	583.6	−.0020	.0024	5.4
−10	23.74	.02393	41.78	1.075	32.11	576.4	−.0021	.0023	5.7
0	30.42	.02419	41.34	1.080	42.92	568.9	−.0022	.0022	6.0
+10	38.51	.02446	40.89	1.085	53.79	561.1	−.0024	.0021	6.4
+20	48.21	.02474	40.43	1.091	64.71	553.1	−.0025	.0020	6.8
30	59.74	.02503	39.96	1.097	75.71	544.8	−.0027	.0019	7.3
40	73.32	.02533	39.49	1.104	86.77	536.2	−.0029	.0018	7.8
50	89.19	.02564	39.00	1.112	97.93	527.3	−.0031	.0017	8.4
60	107.6	.02597	38.50	1.120	109.18	518.1	−.0033	.0015	9.1
70	128.8	.02632	38.00	1.129	120.54	508.6	−.0035	.0013	10.0
80	153.0	.02668	37.48	1.138	131.99	498.7	−.0038	.0011	10.9
90	180.6	.02707	36.95	1.147	143.54	488.5	−.0041	.0009	12.0
+100	211.9	.02747	36.40	1.156	155.21	477.8	−.0045	.0006	13.3
125	307.8	.02860	34.96	(1.189)	(185)	(449)			
150	433.2	.02995	33.39	(1.23)	(216)	(416)			
175	593.5	.03160	31.65	(1.29)	(248)	(377)			
200	794.7	.03375	29.63	(1.38)	(283)	(332)			
250	1347	.0422	23.7	(1.90)	(365)	(192)			

(Abridged from Bur. Standards, Circ. 142, 1923.)

TABLE 295.—Heats of Combustion of Some Carbon Compounds

Given in kg.cal.$_{15}$ at constant pressure per gram-molecular weight in vacuo. When referred to constant volume the values should be 0.58 kg.cal.$_{15}$ smaller (at about 18°C) for each condensed gaseous molecule. Combustion products are CO_2, liquid H_2O, etc. Benzoic acid was adopted at Lyons as a primary standard, its heat of combustion, 6324 g.cal $_{15}$ per gram in air, 6319 in vacuo. This is tacitly assumed as heat of isothermal combustion at 20°C. In absolute joules, 26,466 and 26,445 respectively. The following ratios may be taken as standard: Naphthalene/benzoic acid = 1.5201 (air); benzoic acid/sucrose = 1.6028 (air); napthalene/sucrose = 2.4364 (air). The following values are from Kharasch, Bur. Standards, Journ. Res., 2, 359, 1929, which see for further values.

Compound	Formula	Molecular weight	Kg.cal.$_{15}$ per g.mol.
Methane (g)	CH_4	16	210.8
Ethane (g)	C_2H_6	30	368.4
Propane (g)	C_3H_8	44	526.3
Isobutane (g)	C_4H_{10}	58	683.4
n-Hexane	C_6H_{14}	86.11	990.6
n-Heptane	C_7H_{16}	100.13	1143.6
n-Octane	C_8H_{18}	114.14	1304.2
Decane	$C_{10}H_{22}$	142.18	1610.2
Hexadecane (s)	$C_{16}H_{34}$	226.27	2559.1
Eicosane (s)	$C_{20}H_{42}$	282.34	3183.1
Ethylene (g)	C_2H_4	28	331.6
Propylene (g)	C_3H_6	42	490.2
Isobutylene (g)	C_4H_8	56	647.2
Amylene	C_5H_{10}	70	803.4
Hexylene	C_6H_{12}	84.10	952.6
Acetylene (g)	C_2H_2	26.02	312.0
Allylene (g)	C_3H_4	40	469
Trimethylene (g)	C_3H_6	42	496.8
Benzene	C_6H_6	78.05	782.8
" (v)	"	"	787.2
Toluene	C_7H_8	92.06	935.6
Napthalene (s)	$C_{10}H_8$	128.06	1231.4
Methyl-chloride (g)	CH_3Cl	50.5	168.7
Methylene- " (v)	CH_2Cl_2	85.0	106.8
Chloroform (l)	$CHCl_3$	119.5	89.2
" (v)	"	"	70.3
Carbon-tetrachloride (l)	CCl_4	154.0	37.3
Carbon-tetrachloride (v)	"	"	44.5
Carbon di-sulphide (l)	CS_2	76.0	394.5
" " (v)	"	"	246.6
Methyl alcohol	CH_4O	32.03	170.9
Ethyl "	C_2H_6O	46.05	328.5
Allyl "	C_3H_6O	58.05	442.4

Compound	Formula	Molecular weight	Kg.cal.$_{15}$ per g.mol.
Formaldehyde (g)	CH_2O	30.02	134.1
Acetone (v)	C_3H_6O	58	435.8
Camphor (s)	$C_{10}H_{16}O$	152.13	1411
Sucrose, cane (s)	$C_{12}H_{22}O_{11}$	342.18	1349.6
" milk (s), anhd.	"	"	1350.8
" malt (s)	"	"	1351
Starch			4178.8
Glycogen			4186.8
Cellulose			4180.8
Formic acid	CH_2O_2	46.02	62.8
Acetic "	$C_2H_4O_2$	60.03	208.2
Propionic acid	$C_3H_6O_2$	74.05	367.2
n-butyric "	$C_4H_8O_2$	88.06	524.3
n-valeric "	$C_5H_{10}O_2$	102.08	681.6
Palmitic " (s)	$C_{16}H_{32}O_2$	256.26	2391
Stearic " (s)	$C_{18}H_{36}O_2$	284.29	2700
Lactic " (s)	$C_3H_6O_3$	90.05	326.0
Aniline	C_6H_7N	93.07	813.7
Urea (s)	CH_4N_2O	60.05	151.6
Nicotine	$C_{10}H_{14}N_2$	162.13	1427.7
Cyanogen (g)	C_2N_2	52.0	260.0
Trinitrotoluene (s)	$C_7H_5N_3O_6$	227.06	826
n-propyl "	C_3H_8O	60.06	482.0
n-butyl "	$C_4H_{10}O$	74.08	639.4
n-heptyl "	$C_7H_{16}O$	116.13	1104.9
Octyl "	$C_8H_{18}O$	130.14	1262.0
Cetyl " (s)	$C_{16}H_{34}O$	242.27	2504.5
Menthol (s)	$C_{10}H_{20}O$	156.16	1508.8
Phenol (s)	C_6H_6O	94.05	732.2
Thymol	$C_{10}H_{14}O$	150.11	1353.4
Dimethyl ether (g)	C_2H_6O	46	347.6
Methylethyl " (v)	C_3H_8O	60	503.4
Diethyl " (v)	$C_4H_{10}O$	74.08	660.3

TABLE 296.—Heats of Combustion of Miscellaneous Compounds

Substance.	Small calories per g substance.	Reference.	Substance.	Small calories per g substance.	Reference.
Asphalt	9530	1	Oils: petroleum:		
Butter	9200	–	crude	11500	2
Carbon: amorphous	8080	2	light	10000	2
charcoal	8100	2	heavy	10200	2
diamond	7860	3	rape	9500	6
graphite	7900	3	sperm	10000	7
Copper (to CuO)	590	5	Paraffin (to CO_2, H_2O l)	11140	6
Dynamite, 75%	1290	4	Paraffin (to CO_2, H_2O g)	10340	6
Egg, white of	5700	–	Pitch	8400	–
Egg, yolk of	8100	–	Sulphur, rhombic	2200	2
Fats, animal	9500	2	Sulphur, monoclinic	2240	5
Hemoglobin	5900	–	Tallow	9500	6
Hydrogen	33900	2	Woods: beech, 13% H_2O	4170	8
Iron (to Fe_2O_3)	1582	–	birch, 12% H_2O	4210	8
Magnesium (to MgO)	6080	–	oak, 13% H_2O	3990	8
Oils: cotton-seed	9500	–	pine, 12% H_2O	4420	8
lard	9300	2			
olive	9400	2			

References: (1) Slossen, Colburn; (2) Mean; (3) Berthellot; (4) Roux, Sarran; (5) Thomsen; (6) Stohmann; (7) Gibson; (8) Gottlieb.

Table 297

HEAT VALUES AND ANALYSES OF VARIOUS FUELS

(a) Coals

Coal.		Moisture.	Volatile matter.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calories per gram.	B. T. U.'s per pound.
Lignite	Low grade.	38.81	25.48	27.29	8.42	0.97	7.09	37.45	0.50	45.57	3526	6347
	High grade	33.38	27.44	29.62	9.56	0.94	6.77	41.31	0.67	40.75	3994	7189
Sub-bituminous	Low grade.	22.71	34.78	36.60	5.91	0.29	6.14	52.54	1.03	34.09	5115	9207
	High grade	15.54	33.03	46.06	5.37	0.58	5.89	60.08	1.05	27.03	5865	10557
Bituminous	Low grade.	11.44	33.93	43.92	10.71	4.94	5.39	60.06	1.02	17.88	6088	10958
	High grade	3.42	34.36	58.83	3.39	0.58	5.25	77.98	1.29	11.51	7852	14134
Semi-bituminous	Low grade	2.7	14.5	75.5	7.3	0.99	4.58	80.65	1.82	4.66	7845	14121
	Highgrade	3.26	14.57	78.20	3.97	0.54	4.76	84.62	1.02	5.09	8166	14699
Semi-anthracite		2.07	9.81	78.82	9.30	1.74	3.62	80.28	1.47	3.59	7612	13702
Anthracite	Low grade.	2.76	2.48	82.07	12.69	0.54	2.23	79.22	0.68	4.64	6987	12577
	High grade	3.33	3.27	84.28	9.12	0.60	3.08	81.35	0.79	5.06	7417	13351
Oven coke	Low grade.	1.92	1.58	88.87	8.99	1.18	—	—	—	—	7946	14300
	High grade	1.14	0.04	94.66	3.57	0.69	—	—	—	—	8006	14410

(b) Peats and Woods (air dried)

	Vol. hydro-carbon.	Fixed carbon.	Ash.	Sul-phur.	Hydro-gen.	Carbon.	Nitro-gen.	Oxygen.	Calories per gram.	B.T.U.'s per pound.
Peats:										
Franklin Co., N. Y.	67.10	28.99	3.91	0.15	5.93	57.17	1.48	31.36	5726	10307
Sawyer Co., Wis.	56.54	27.92	15.54	0.29	4.71	51.00	1.92	26.54	4867	8761
Woods:										
Oak, dry	—	—	0.37	—	6.02	50.16	0.09	43.36	4620	8316
Birch, dry	—	—	0.29	—	6.06	48.88	0.10	44.67	4771	8588
Pine, dry	—	—	0.37	—	6.20	50.31	0.04	43.08	5085	9153

(c) Liquid Fuels

Fuel.	Specific gravity at 15° C.	Calories per gram.	British thermal units per pound.
Petroleum ether	.684–.694	12210–12220	21978–21996
Gasoline	.710–.730	11100–11400	19980–20520
Kerosene	.790–.800	11000–11200	19800–20160
Fuel oils, heavy petroleum or refinery residue	.960–.970	10200–10500	18360–18900
Alcohol, fuel or denatured with 7 to 9 per cent water and denaturing material	.8196–.8202	6440–6470	11592–11646

(d) Gases

Gas.	H_2	CH_4	C_2H_2	Illuminants.	CO_2	CO	O_2	N_2	Cal. per m^3	B.T.U. per cu. ft.
Natural gas, Cal.	—	88.0	—	—	11.10	—	—	0.90	8339	937
Natural gas, Pa.	—	53.3	45.8*	—	—	—	—	0.90	12635	1420
Natural gas, France	—	98.81	—	—	0.58	—	0.1	0.48	9364	1052
Coal gas, high grade	34.80	28.80	9.50	1.70	0.20	10.40	0.40	14.20	6151	657
Coal gas, low grade	57.2	18.8	—	0.8	2.00	3.20	—	18.0	3736	399
Water gas, low grade	52.88	2.16	—	3.47	—	36.8	—	4.69	2642	283
Water gas, high grade	36.4	23.2	—	14.05	3.02	19.1	1.15	3.08	6140	657

* C_2H_6. Data from the Geological Survey, Poole's The Calorific Power of Fuels, and for natural gas from Snelling (Van Nostrand's Chemical Annual).

CHEMICAL AND PHYSICAL PROPERTIES OF FIVE DIFFERENT CLASSES OF EXPLOSIVES

Explosive.	Specific gravity.	Number of large calories developed by 1 kilogram of the explosive.	Pressure developed in own volume after elimination of surface influence.	Unit disruptive charge by ballistic pendulum.	Rate of detonation. Cartridges 1¼ in. diam.	Duration of flame from 100 grams of explosive.	Length of flame from 100 grams.	Cartridge 1¼ in. transmitted explosion at a distance of	Products of combustion from 200 grams; gaseous, solid, and liquid, respectively.	Ignition occurred in 4% firedamp & coal dust mixture with
			Kg per sq. cm.	Grams.	Meters per second.	Millisec-onds.	Inches.	Inches.	Grams.	Grams.
(A) Forty-per-cent nitroglycerin dynamite	1.22	1221.4	8235	227*	4688	.358	24.63	12	88.4 79.7 14.5	25
(B) FFF black blasting powder	1.25	789.4	4817	374† 458*	469.1‡	925.	54.32	–	154.4 126.9 4.1‖	25
(C) Permissible explosive; nitroglycerin class	1.10	760.5	5912	301*	3008	.471	27.79	4	103.9 65.1 15.4	1000
(D) Permissible explosive; ammonium nitrate class	0.97	992.8	7300	279*	3438§	.483	25.68	1	89.8 27.5 75.5	800
(E) Permissible explosive; hydrated class	1.54	610.6	6597	434*	2479	.338	17.49	3	86.1 56.0 33.0	Over 1000

Chemical Analyses.

(A) Moisture	0.91
Nitroglycerin	39.68
Sodium nitrate	42.46
Wood pulp	13.58
Calcium carbonate	3.37
(B) Moisture	0.80
Sodium nitrate	70.57
Charcoal	17.74
Sulphur	10.89
(C) Moisture	7.89
Nitroglycerin	24.02
Sodium nitrate	36.25
Wood pulp and crude fibre from grains	9.20
Starch	21.31
Calcium carbonate	0.97
Magnesium "	0.36
(D) Moisture	0.23
Ammonium nitrate	83.10
Sulphur	0.46
Starch	2.61
Wood pulp	1.89
Poisonous matter	2.54
Manganese peroxide	2.64
Sand	6.53
(E) Moisture	2.34
Nitroglycerin	30.85
Ammonium nitrate	9.94
Sand	1.75
Coal	11.98
Clay	7.64
Ammonium sulphate	8.96
Zinc sulphate (7HO)	6.89
Potassium sulphate	19.65

* One pound of clay tamping used. † Two pounds of clay tamping used. ‡ Rate of burning.
§ Cartridges 1¾ in. diam. ‖ For 300 grammes.

Compiled from U. S. Geological Survey Results, — "Investigation of Explosives for use in Coal Mines, 1909."

TABLE 299.—Additional Data on Explosives

Explosive. (Ref. Young, Nature, 102, 216, 1918.)	Vol. gas per g in cc = V	Calories per g = Q	Coefficient = QV ÷ 1000	Coefficient GP = 1	Calculated Temperature Q/C C, sp. ht. gases = 0.24
	cc				
Gunpowder	280	738	207	1	2240° C
Nitroglycerine	741	1652	1224	6	6880
Nitrocellulose, 13% N_2	923	931	859	4.3	3876
Cordite, Mk. I. (NG. 57; NC, 38; Vaseline, 5)	871	1242	1082	5.2	5175
Cordite, MD (NG, 30; NC, 65; Vaseline, 5)	888	1031	915	4.4	4225
Ballistite (NG, 50; NC, 50; Stabilizer, 5)	817	1349	1102	5.3	5621
Picric acid (Lyddite)	877	810	710	3.4	3375

Shattering power of explosive = vol. gas per g × cals./g × V_d × density where V_d is the velocity of detonation.
Trinitrotoluene: V_d = 7000 m/sec. Shattering effect = .87 picric acid.
Amatol (Ammonium nitrate + trinitrotoluene, TNT): V_d = 4500 m/sec.
Ammonal (Ammonium nitrate, TNT, Al): 1578 cal/g; 682 cc gas; V_d = 4000 m/sec.
Sabulite (Ammonium nitrate, 78, TNT 8, Ca silicide 14): about same as ammonal.

TABLE 300.—Ignition Temperatures of Gaseous Mixtures

Ignition temperature taken as temperature necessary for hot body immersed in gas to cause ignition; slow combination may take place at lower temperatures. McDavid, J. Ch. Soc. Trans. 111, 1003, 1917. Gases were mixed with air. Practically same temperatures as with O_2 (Dixon, Conrad, *loc. cit.* 95, 1909).

Benzene and air	1062° C	Ether and air	1033° C
Coal gas and air	878	Ethylene and air	1000
CO and air	931	Hydrogen and air	747

TABLE 301.—Time of Heating for Explosive Decomposition

Temperature ° C.	170	180	190	200	220	Ignition temperature.	
Time.	sec.	sec.	sec.	sec.	sec.	° C †	° C‡
Black powder	*n*	*n*	*n*	*n*	*n*	440	—
Smokeless powder A	600	195	130	45	23	{ 300	—
Smokeless powder B	190	130	—	90	25		—
Celluloid Pyroxylin	170	60	—	21	9	—	—
Collodion cotton	870	165	67	56	18	300	—
Celluloid *	160	100	60	50	30	590	450
Safety matches	*n*	340	240	150	60	—	—
Parlor matches	*n*	*n*	*n*	590	480	—	—
Cotton wool	—	—	—	—	—	900	—

n, failure to explode in twenty minutes. * The decomposition of nitrocellulose in celluloid commences at about 100° C; above that the heat of decomposition may raise the mass to the ignition point if loss of heat is prevented. Above 170°, decomposition occurs with explosive violence as with nitrocellulose. Rate of combustion is 5 to 10 times that of poplar, pine, or paper of the same size and conditions.
† Measured by contact with porcelain tube of given temperature. Average.
‡ Measured by contact with molten lead. Average.
Taken from Technologic Paper of Bureau of Standards, No. 98, 1917.

TABLE 302.—Flame Temperatures

Measures made with optical pyrometer by Féry, J. de Phys. (4) 6, 1907.

Alcohol, with NaCl	1705° C	Hydrogen flame	1900° C
Bunsen flame, no air	1712	Hydrogen-oxygen	2420
Bunsen flame, ½ air	1812	Acetylene burner	2458
Bunsen flame, full air	1871	Acetylene-oxygen	3000
Illuminating gas-oxygen	2200	Cooper-Hewlit Hg	3500

THERMOCHEMISTRY. CHEMICAL ENERGY DATA

The total heat generated in a chemical reaction is independent of the steps from initial to final state. Heats of formation may therefore be calculated from steps chemically impracticable. Chemical symbols now represent the chemical energy in a gram-molecule or mol(e); treat reaction equations like algebraic equations: $CO + O = CO_2 + 68$ Kg-cal; subtract $C + 2\,O = CO_2 + 97$ Kg-cal, then $C + O = CO + 29$ Kg-cal. We may substitute the negative values of the formation heats in an energy equation and solve $MgCl_2 + 2\,Na = 2\,NaCl + Mg + x$ Kg-cal; $-151 = -196 + x$; $x = 45$ Kg-cal. Heats of formation of organic compounds can be found from the heats of combustion since burned to H_2O and CO_2. When changes are at constant volume, energy of external work is negligible; also generally for solid or liquid changes in volume. When a gas forms a solid or liquid at constant pressure, or vice versa, it must be allowed for. For N mols of gas formed (disappearing) at $T_K°$ the energy of the substance is decreased (increased) by $0.002 \cdot N \cdot T_K$ Kg-cal. $H_2 + O = H_2O + 67.5$ Kg-cal. at 18°C at constant volume; $\frac{1}{2}(2\,H_2 + O_2 - 2\,H_2O = 135.0 + 0.002 \times 3 \times 291 = 136.7) = 68.4$ Kg-cal.

The heat of solution is the heat, + or —, liberated by the solution of 1 mol of substance in so much water that the addition of more water will produce no additional heat effects. Aq. signifies this amount of water; H_2O, one mol.; $NH_3 + Aq = NH_4OH \cdot Aq. + 8$ Kg-cal.

Heats of Formation from Elements in Kilogram-Calories

At ordinary temperatures.

Compound.	Heat of Formation.	Compound.	Heat of Formation.	Compound.	Heat of Formation.	Compound.	Heat of Formation.
Al_2O_3	380.	HgO	21.4	KCl	105.7	Li_2SO_4	334.2
Ag_2O	6.5	Na_2O	100.	$LiCl$	93.8	$(NH_4)_2SO_4$	283.
BaO	126.	Nd_2O_3	435.	$MgCl_2$	151.0	Na_2SO_4	328.3
BaO_2	142.	NiO	57.9	$MnCl_2$	112.3	$MgSO_4$	301.6
Bi_2O_3	138.	P_2O_5 sgs	370.	$NaCl$	97.8	$PbSO_4$	216.2
CO am	29.0	PbO	50.3	$NdCl_3$	250.	Tl_2SO_4	221.0
CO di	26.1	PbO_2	62.4	NH_4Cl	76.3	$ZnSO_4$	229.6
CO_2 am	97.0	Pr_2O_3	412.	$NiCl_2$	74.5	$CaCO_3$	270.
CO_2 gr	94.8	Rb_2O	89.2	$PbCl_2$	83.4	$CuCO_3$	143.
CO_2 di	94.3	SO_2 rh sgg	70.	$PdCl_2$	40.5	$FeCO_3$	179.
CaO	152.	SiO_2	191.0	$PtCl_4$	60.4	K_2CO_3	280.
CeO_2	225.	SnO	66.9	$SnCl_2$	80.8	$MgCO_3$	267.
Cl_2O g	−16.5	SnO_2 cr	137.5	$SnCl_4$	128.	Na_2CO_3	272.
CoO am	50.5	SrO_2	135.	$SrCl_2$	185.	$ZnCO_3$	194.
CoO cr	57.5	ThO_2	326.	$ThCl_4$	300.	$AgNO_3$	28.7
Co_3O_4	193.4	TiO_2 am	215.6	$TlCl$	48.6	$Ca(NO_3)_2$	209.
CrO_3	140.	TiO_2 cr	218.4	$RbCl$	105.9	$Cu(NO_3)_2 6\,H_2O$	92.9
Cs_2O	91.3	TlO_2	42.2	$ZnCl_2$	97.3	HNO_3 gggl	41.6
Cu_2O	42.3	WO_2	131.	HBr glg	8.6	KNO_3	119.2
CuO	37.2	WO_3	194.	NH_4Br	66.	$LiNO_3$	112.
FeO	65.7	ZnO	85.2	HI gsg	−6.2	NH_4NO_3	88.3
Fe_2O_3	196.5	$AgCl$	29.2	HF ggg	38.	$NaNO_3$	111.0
Fe_3O_4	270.8	Ag_2Cl	29.5	Ag_2S	3.3	$TlNO_3$	58.2
H_2O ggl	68.4	$AlCl_3$	161.4	CS_2 sgg	−26.0	CH_4 sgg	20.
H_2O_2 ggl	46.8	$AuCl$ y	5.81	CaS	90.8	C_2H_6 sgg	25.
Hg_2O	22.2	$AuCl_3$ y	22.8	$(NH_4)_2S$	66.2	C_2H_2 sgg	−53.
HgO	21.4	$BaCl_2$	197.	Cu_2S	18.3	HCN di gsgg	−30.5
K_2O	91.	$BiCl_3$	90.6	CuS	11.6	NH_3 ggg	12.0
La_2O_3	447.	CCl_4 am	21.0	H_2S gsg	2.73	$Ca(OH)_2$	230.
LiO_2	141.6	$CaCl_2$	187.	K_2S	103.4	NH_4OH	88.8
MgO	143.6	$CdCl_2$	93.2	MgS	79.4	$NaOH$	102.
MnO	90.8	$CoCl_2$	76.5	Na_2S	89.3	$Na \cdot H_2O \cdot Aq - H$	44.*
MnO_2	123.	$CuCl_2$	51.5	PbS	19.3	$\frac{1}{2}(2\,Na \cdot O \cdot H_2O)$	68.*
Mn_3O_4	325.	$CuCl$	34.1	$CaSO_4$	262.	$\frac{1}{2}(Na_2O \cdot H_2O \cdot Aq)$	30.*
MoO_2	143.	$FeCl_2$	82.1	$CuSO_4$	111.5	KOH	103.5
MoO_3	174.	$FeCl_3$	96.0	H_2SO_4 sggg	193.	$K \cdot H_2O \cdot Aq - H$	45.*
N_2O ggg	−18.2	$GlCl_2$	155.	$-SO_3 \cdot H_2O$*	21.3	$\frac{1}{2}(2\,K \cdot O \cdot H_2O)$	69.*
NO ggg	−21.6	HCl ggl	22.	Hg_2SO_4	175.	$\frac{1}{2}(K_2O \cdot H_2O \cdot Aq)$	35.5*
NO_2	− 8.1	$HgCl$	31.3	$HgSO_4$	165.		
Na_2O_4	− 2.6	$HgCl_2$	53.3	K_2SO_4	344.3		

am = amorphous; di = diamond; gr = graphite; cr = crystal; g = gas; l = liquid; s = solid; y = yellow (gold); rh = rhombic (sulphur). * Heats of formation not from elements but as indicated.

TABLE 304.—Heats of Formation of Ions in Kilogram-Calories

+ and — signs indicate signs of ions and the number of these signs the valency. For the ionisation of each gram-molecule of an element divide the numbers in the table by the valency, e. g., 9.03 gr. Al = 9.03 gr. Al^{+} + 40.3 Kg. cal. When a solution is of such dilution that further dilution does not increase its conductivity, then the heats of formation of substances in such solutions may be found as follows: $FeCl_2Aq$ = + 22.2 + 2 × 39.1 = 100.4 Kg. cal. $CuSO_4Aq$ = — 15.8 + 214.0 = 198.2 Kg. cal.

Ag +	— 25.3	NH_4+	+ 32.7	AsO_4 — — —	+ 215.0	IO_3 —	+ 55.8
Al + + +	+ 121.0	NH_4O+	+ 37.5	Br —	+ 28.2	IO_4 —	+ 46.5
Co + +	+ 170.0	Na +	+ 57.3	BrO_3 —	+ 11.2	OH —	+ 54.4
Ca + +	+ 133.?	Ni + +	+ 16.0	CO_3 — —	+ 160.8	PO_4 — — —	+ 298.0
Cd + +	+ 18.4	Mg + +	+ 108.8	Cl —	+ 39.1	S_2O_3 — —	+ 138.6
Cu + +	— 16.0	Mn + +	+ 50.2	ClO —	+ 26.0	S_2O_6 — —	+ 278.2
Cu +	— 15.8?	Pb + +	+ 4.0	ClO_3 —	+ 23.4	S_4O_6 — —	+ 260.8
Fe + +	+ 22.2	Rb +	+ 625.0	ClO_4 —	— 38.7	SO_3 — —	+ 151.0
Fe + + +	— 9.3	Sn + + + +	+ 3.3	HCO_3 —	+ 163.0	SO_4 — —	+ 214.0
H +	0.0	Sr + +	+ 119.6	HPO_2 —	+ 143.9	Se — —	— 35.6
Hg +	— 19.8	Tl +	+ 1.7	HPO_3 — —	+ 229.6	SeO_3 — —	+ 119.6
K +	+ 61.8	Zn + +	+ 35.0	HPO_4 — —	+ 304.8	SeO_4 — —	+ 144.8
Li +	+ 62.8			HS —	+ 1.2	Te — —	— 34.8
				NO_2 —	+ 27.0	TeO_3 — —	+ 77.0
				NO_3 —	+ 48.9	TeO_4 — —	+ 98.4
				I —	+ 13.1	S — —	— 12.6

TABLE 305.—Heats of Neutralization in Kilogram-Calories

The heat generated by the neutralization of an acid by a base is equal, for each gram-molecule of water formed, to 13.7 Kg. cal. plus the heat produced by the amount of un-ionized salt formed, plus the sum of the heats produced in the completion of the ionizations of the acid and the base.

Base.	HCl·aq	HNO_3·aq	H_2SO_4·aq	HCN·aq	CH_3COOH·aq	H_2·CO_3·aq
KOH · aq	13.7	13.8	15.7	2.9	13.3	10.1
NaOH · aq	13.7	13.7	15.7	2.9	13.3	10.2
NH_4OH · aq	12.4	12.5	14.5	1.3	12.0	8.
½ $Ca(OH)_2$ · aq	14.0	13.9	15.6	3.2	13.4	9.5
½ $Zn(OH)_2$ · aq	9.9	9.9	11.7	8.1	8.9	5.5
½ $Cu(OH)_2$ · aq	7.5	7.5	9.2	—	6.2	—

TABLE 306.—Heats of Dilution of H_2SO_4

In Kilogram-calories by the dilution of one gram-molecule of sulphuric acid by m gram molecules of water.

m	1	2	3	5	19	49	99	199	399	1599
Kg. Cal. . .	6.38	9.42	11.14	13.11	16.26	16.68	16.86	17.06	17.31	17.86

TABLE 307.—Radiation Constants and Formulae for Black Body

The radiation per cm² from a "black body" (exclusive of convection losses) at the temperature $T°$ K. (Centigrade degrees) to one at T_0°K. is $J = \sigma\ (T^4 - T_0^4)$, (Stefan. Boltzman) where $\sigma = 2\pi^5 k^4/15\ c^2\ h^3 = (5.713_9 \pm 0.006) \times 10^{-5}$ erg·cm⁻²·deg.⁻⁴ sec.⁻¹ (Birge) (indirect)
$= (5.735 \pm 0.011) \times 10^{-5}$ erg·cm⁻²·deg.⁻⁴sec.⁻¹(Birge) (experimental).

The distribution of this energy in the spectrum is represented by Planck's formula:

$$J_\lambda = c_1 \lambda^{-5} \left(e^{\frac{c_2}{\lambda T}} - 1\right)^{-1} d\lambda$$

where J_λ represents the intensity at wave length λ

$*c_1 = (3.697 \pm 0.005) \times 10^{-5}$ erg·cm²·sec.⁻¹, unpolarized radiation over solid angle 2π.
$= (3.194 \pm 0.004)$ erg·cm²· day⁻¹
$= (8.832 \pm 0.01) \times 10^{-13}$ g cal.$_{15}$ cm²· deg.
$= (3.697 \pm 0.005) \times 10^{-12}$ watts·cm²
$c_2 = (1.432 \pm 0.003)$ cm·deg.
J max. $= 3.11 \times 10^{-6}\ T^5$
λ max $T = c_2/4.9651 = (0.28836 \pm 0.00011)$ cm·deg.

$*c_1 = 2\pi hc^2 = 3.697 \times 10^{-5}$ erg·cm²·sec.⁻¹ when $E_\lambda d\lambda$ denotes the emission of unpolarized radiation in range $d\lambda$, per unit surface in all directions (2π solid angle).

$c_1 = 8\pi hc = 4.932 \times 10^{-15}$ cm·deg., when $E_\lambda d\lambda$ denotes energy density of unpolarized radiation.

$c_1 = hc^2 = 0.5884 \times 10^{-5}$ erg·cm²·sec.⁻¹, when $E_\lambda d\lambda$ denotes intensity of linearly polarized radiation in range $d\lambda$, perpendicularly to a surface, per unit surface, per unit solid angle.

TABLE 308.—Radiation in ergs ($R \times 10^n$) and gram-calories ($R^1 \times 10^n$) per cm² per sec. from a perfect radiator at t°C to absolutely cold space (— 273°C)

Computed from Stefan-Boltzman formula, $\sigma = 5.73 \times 10^{-5}$ erg. cm.⁻²deg.⁻⁴

Temp. °C	erg/cm²/sec. R	n	cal./cm²/sec. R^1	n	Temp. °C	erg/cm²/sec. R	n	cal./cm²/sec. R^1	n	Temp. °C	erg/cm²/sec. R	n	cal./cm²/sec. R^1	n
−270	5.29	−3	1.27	−10	4	3.38	5	8.11	−3	58	6.89	5	1.65	−2
−250	1.61	1	3.86	−7	6	3.48	5	8.35	−3	60	7.05	5	1.69	−2
−200	1.64	3	3.94	−5	8	3.58	5	8.59	−3	70	7.94	5	1.91	−2
−190	2.73	3	6.55	−5	10	3.68	5	8.83	−3	80	8.91	5	2.14	−2
−180	4.31	3	1.03	−4	12	3.78	5	9.07	−3	90	9.96	5	2.39	−2
−160	9.37	3	2.25	−4	14	3.89	5	9.33	−3	100	1.11	6	2.66	−2
−150	1.31	4	3.14	−4	16	4.00	5	9.60	−3	200	2.87	6	6.89	−2
−140	1.82	4	4.37	−4	18	4.11	5	9.86	−3	300	6.18	6	1.48	−1
−130	2.40	4	5.76	−4	20	4.22	5	1.01	−2	400	1.18	7	2.83	−1
−120	3.15	4	7.56	−4	22	4.34	5	1.04	−2	500	2.05	7	4.92	−1
−110	4.05	4	9.72	−4	24	4.46	5	1.07	−2	600	3.33	7	7.99	−1
−100	5.15	4	1.24	−3	26	4.59	5	1.10	−2	700	5.14	7	1.23	0
−90	6.44	4	1.55	−3	28	4.71	5	1.13	−2	800	7.60	7	1.82	0
−80	7.97	4	1.91	−3	30	4.84	5	1.16	−2	900	1.11	8	2.66	0
−70	9.74	4	2.34	−3	32	4.96	5	1.19	−2	1000	1.50	8	3.60	0
−60	1.18	5	2.83	−3	34	5.10	5	1.22	−2	1500	5.66	8	1.36	+1
−50	1.42	5	3.41	−3	36	5.23	5	1.26	−2	2000	1.53	9	3.67	+1
−40	1.69	5	4.06	−3	38	5.37	5	1.29	−2	3000	6.57	9	1.58	+2
−30	2.00	5	4.80	−3	40	5.51	5	1.32	−2	4000	1.91	10	4.58	+2
−20	2.35	5	5.64	−3	42	5.65	5	1.36	−2	5000	4.43	10	1.06	+3
−10	2.74	5	6.58	−3	44	5.79	5	1.39	−2	6000	8.87	10	2.13	+3
−8	2.83	5	6.79	−3	46	5.94	5	1.42	−2	7000	1.63	11	3.91	+3
−6	2.92	5	7.01	−3	48	6.09	5	1.46	−2	8000	2.68	11	6.43	+3
−4	3.00	5	7.20	−3	50	6.24	5	1.50	−2	9000	4.24	11	1.02	+4
−2	3.09	5	7.42	−3	52	6.40	5	1.54	−2	10000	6.38	11	1.53	+4
0	3.19	5	7.66	−3	54	6.56	5	1.57	−2	15000	3.12	12	7.49	+4
+2	3.28	5	7.87	−3	56	6.72	5	1.61	−2	20000	9.68	12	2.32	+5
										25000	2.34	13	5.62	+5

NOTE: Above table correct probably to one per cent.

Table 309

BLACK-BODY SPECTRUM INTENSITIES ($J\lambda$), 50° TO 20000°K.

Values of $J\lambda$ using for C_1, 9.23×10^3, C_2, 14350., λ in μ. If the figures given for $J\lambda$ are plotted in cms as ordinates to a scale of abscissae of 1 cm to 1 μ, then the area in cm² between the smooth curve through the resulting points and the axis of abscissae is equivalent to the radiation in calories per sec. from 1 cm² of a black body at the corresponding temperature, radiating to absolute zero. The intensities when radiating to a body at a lower temperature may be obtained by subtracting the intensities corresponding to the lower temperature from those of the higher. The nature of the black-body formula is such that when λT is small, a small change in C_2 produces a great change in $J\lambda$; e.g., when $C_2/\lambda T$ is 100 or 10, the change is 100 and 10 fold respectively; as λT increases, the change becomes proportional; e.g., when $C_2/\lambda T$ is less than 0.05, the change in $J\lambda$ is proportional to the change in C_2.

λ (μ)	50° K.	100° K.	150° K.	200° K.	250° K.	273° K.	300° K.	373° K.	400° K.	500° K.	600° K.
1.0	—	$.0_{58}3$	$.0_{37}2$	$.0_{27}6$	$.0_{20}1$	$.0_{18}1$	$.0_{16}1$	$.0_{12}2$	$.0_{11}24$	$.0_{8}31$	$.0_{6}38$
1.5	—	$.0_{38}3$	$.0_{24}2$	$.0_{17}2$	$0_{13}3$	$.0_{12}7$	$.0_{10}2$	$.0_{8}8$	$.0_{7}49$	$.0_{5}58$	$.0_{3}143$
2.0	$.0_{59}1$	$.0_{28}2$	$.0_{18}5$	$.0_{13}7$	$.0_{9}1$	$.0_{9}11$	$.0_{7}12$	$.0_{5}13$	$.0_{5}46$	$.0_{3}168$	.00184
2.5	$.0_{47}1$	$.0_{22}1$	$.0_{14}2$	$.0_{10}3$	$.0_{7}10$	$.0_{7}7$	$.0_{6}46$	$.0_{4}19$	$.0_{4}50$	$.0_{3}97$	.0066
3.0	$.0_{40}9$	$.0_{19}6$	$.0_{12}5$	$.0_{8}2$	$.0_{6}18$	$.0_{6}9$	$.0_{5}45$	$.0_{3}102$	$.0_{3}242$	.00265	.0131
3.5	$.0_{34}4$	$.0_{16}3$	$.0_{10}2$	$.0_{7}2$	$.0_{6}13$	$.0_{5}5$	$.0_{4}20$	$.0_{3}29$	$.0_{3}620$	.00482	.0189
4.0	$.0_{30}6$	$.0_{14}2$	$.0_{9}4$	$.0_{6}14$	$.0_{5}52$	$.0_{4}18$	$.0_{4}57$	$.0_{3}60$	.00115	.00690	.0229
5.0	$.0_{24}3$	$.0_{11}1$	$.0_{7}14$	$.0_{5}17$	$.0_{4}30$	$.0_{4}8$	$.0_{3}21$	.00134	.00226	.00952	.0249
6.0	$.0_{20}19$	$.0_{10}5$	$.0_{6}14$	$.0_{5}8$	$.0_{4}8$	$.0_{3}18$	$.0_{3}41$	.00195	.00301	.01001	.0224
7.0	$.0_{18}83$	$.0_{9}6$	$.0_{6}6$	$.0_{4}19$	$.0_{3}15$	$.0_{3}30$	$.0_{3}59$	.00225	.00328	.00925	.0186
8.0	$.0_{16}72$	$.0_{8}5$	$.0_{5}18$	$.0_{4}36$	$.0_{3}22$	$.0_{3}39$	$.0_{3}71$	.00232	.00321	.00801	.0149
9.0	$.0_{14}22$	$.0_{7}18$	$.0_{5}38$	$.0_{4}54$	$.0_{3}27$	$.0_{3}45$	$.0_{3}77$	.00220	.00295	.00672	.0118
10.0	$.0_{13}31$	$.0_{7}54$	$.0_{5}65$	$.0_{4}71$	$.0_{3}30$	$.0_{3}48$	$.0_{3}78$	.00201	.00262	.00554	.00929
12.0	$.0_{11}15$	$.0_{6}24$	$.0_{4}13$	$.0_{4}94$	$.0_{3}31$	$.0_{3}47$	$.0_{3}70$	.00157	.00196	.00374	.00585
14.0	$.0_{10}21$	$.0_{6}61$	$.0_{4}18$	$.0_{4}102$	$.0_{3}29$	$.0_{3}41$	$.0_{3}58$	.00117	.00144	.00254	.00380
16.0	$.0_{9}14$	$.0_{5}11$	$.0_{4}22$	$.0_{4}100$	$.0_{3}25$	$.0_{3}34$	$.0_{3}46$	$.0_{3}87$	.00105	.00176	.00254
18.0	$.0_{9}57$	$.0_{5}17$	$.0_{4}24$	$.0_{4}92$	$.0_{3}21$	$.0_{3}28$	$.0_{3}368$	$.0_{3}653$	$.0_{3}760$	.00124	.00176
20.0	$.0_{8}16$	$.0_{5}22$	$.0_{4}24$	$.0_{4}82$	$.0_{3}17$	$.0_{3}224$	$.0_{3}290$	$.0_{3}493$	$.0_{3}575$	$.0_{3}902$	.00125
25.0	$.0_{8}97$	$.0_{5}30$	$.0_{4}21$	$.0_{4}57$	$.0_{3}122$	$.0_{3}131$	$.0_{3}164$	$.0_{3}258$	$.0_{3}295$	$.0_{3}439$	$.0_{3}589$
30.0	$.0_{7}26$	$.0_{5}32$	$.0_{4}16$	$.0_{4}38$	$.0_{4}66$	$.0_{4}79$	$.0_{4}97$	$.0_{3}146$	$.0_{3}164$	$.0_{3}237$	$.0_{3}311$
40.0	$.0_{7}69$	$.0_{5}26$	$.0_{5}9$	$.0_{4}18$	$.0_{4}282$	$.0_{4}33$	$.0_{4}391$	$.0_{4}558$	$.0_{4}620$	$.0_{4}858$	$.0_{3}110$
50.0	$.0_{7}95$	$.0_{5}18$	$.0_{5}51$	$.0_{5}92$	$.0_{4}150$	$.0_{4}158$	$.0_{4}184$	$.0_{4}255$	$.0_{4}281$	$.0_{4}381$	$.0_{4}482$
75.0	$.0_{7}87$	$.0_{6}67$	$.0_{5}15$	$.0_{5}24$	$.0_{5}338$	$.0_{5}383$	$.0_{5}436$	$.0_{5}580$	$.0_{5}634$	$.0_{5}834$	$.0_{4}103$
100.0	$.0_{7}55$	$.0_{6}29$	$.0_{6}57$	$.0_{6}88$	$.0_{5}119$	$.0_{5}134$	$.0_{5}150$	$.0_{5}197$	$.0_{5}214$	$.0_{5}277$	$.0_{5}342$

λ (μ)	800° K.	1000° K.	1500° K.	2000° K.	3000° K.	4000° K.	5000° K.	6000° K.	8000° K.	10000° K.	20000° K.
0.1	—	—	—	$0.0_{22}6$	$0.0_{11}15$	$0.0_{6}24$	$0.0_{3}31$	0.038	15.	540.	710000.
0.2	—	—	—	$0.0_{8}7$	0.0012	0.46	15.4	184.	3660.	22100.	820000.
0.3	—	—	—	$0.0_{3}15$	0.44	24.2	263.	1310.	9640.	31000.	382000.
0.4	—	—	—	0.0145	5.75	115.	690.	2280.	10300.	25600.	180000.
0.5	—	—	—	0.172	20.6	226.	952.	2490.	8400.	17800.	92300.
0.6	—	$.0_{5}48$	0.014	0.757	40.8	301.	1000.	2240.	6290.	11950.	51460.
0.7	$.0_{6}40$	$.0_{4}68$	0.064	1.93	59.2	328.	925.	1860.	4590.	8110.	30700.
0.8	$.0_{5}51$	.00045	0.180	3.58	71.5	321.	800.	1490.	3350.	5620.	19400.
0.9	$.0_{4}34$	.00183	0.378	5.35	77.3	295.	671.	1177.	2470.	3980.	12820.
1.0	.00015	.00538	0.645	7.06	77.8	262.	554.	928.	1842.	2880.	8800.
1.5	.0775	.0848	2.07	10.25	52.2	122.	210.	309.	527.	758.	1980.
2.0	.0367	.221	2.43	8.19	29.0	57.6	90.2	125.	198.	275.	668.
2.5	.0719	.305	2.10	5.68	16.4	29.5	43.9	58.9	90.1	121.9	284.
3.0	.0964	.320	1.64	3.82	9.66	16.4	23.7	31.1	46.4	61.9	140.7
3.5	.1050	.296	1.22	2.60	6.02	9.84	13.8	17.9	26.3	34.7	77.3
4.0	.1027	.256	0.907	1.80	3.90	6.20	8.59	11.0	15.9	20.9	45.9
5.0	.0839	.178	0.511	0.923	1.84	2.81	3.81	4.81	6.84	8.89	19.15
6.0	.0629	.119	0.302	0.514	0.973	1.45	1.935	2.42	3.40	4.39	9.34
7.0	.0459	.0811	0.188	0.307	0.560	0.820	1.165	1.348	1.88	2.41	5.09
8.0	.0335	.0562	0.122	0.194	0.344	0.498	0.653	0.808	1.20	1.43	3.00
9.0	.0247	.0398	0.0824	0.128	0.223	0.319	0.416	0.513	0.709	0.90	1.87
10.0	.0184	.0288	0.0575	0.0880	0.151	0.214	0.278	0.342	0.470	0.598	1.24
12.0	.01072	.0160	0.0304	0.0553	0.0757	0.107	0.1373	0.168	0.230	0.292	0.602
14.0	.00660	.0096	0.0175	0.0256	0.0421	0.0587	0.0754	0.0921	0.125	0.159	0.326
16.0	.00425	.00606	0.0108	0.0155	0.0253	0.0350	0.0448	0.0546	0.0742	0.0938	0.192
18.0	.00285	.00400	0.00697	0.00997	0.0160	0.0221	0.0282	0.0344	0.0466	0.0585	0.120
20.0	.00198	.00275	0.00470	0.00668	0.01068	0.0147	0.01868	0.0227	0.0307	0.0388	0.0789
25.0	.00090	.00122	0.00203	0.00284	0.00448	0.00612	0.00777	0.00941	0.0127	0.0160	0.0325
30.0	$.0_{3}464$	$.0_{3}619$	0.00101	0.00141	0.00220	0.00299	0.00378	0.00455	0.00616	0.00775	0.0157
40.0	$.0_{3}159$	$.0_{3}209$	$0.0_{3}334$	$0.0_{3}459$	$0.0_{3}710$	$0.0_{3}960$	0.00121	0.00146	0.00197	0.00247	0.00498
50.0	$.0_{4}684$	$.0_{4}888$	$0.0_{3}140$	$0.0_{3}191$	$0.0_{3}294$	$0.0_{3}397$	$0.0_{3}500$	$0.0_{3}603$	$0.0_{3}808$	0.00101	0.00204
75.0	$.0_{4}144$	$.0_{4}184$	$0.0_{4}286$	$0.0_{4}387$	$0.0_{4}591$	$0.0_{4}794$	$0.0_{4}997$	$0.0_{3}120$	$0.0_{3}161$	$0.0_{3}201$	$0.0_{3}406$
100.0	$.0_{5}470$	$.0_{5}598$	$0.0_{5}919$	$0.0_{4}124$	$0.0_{4}188$	$0.0_{4}252$	$0.0_{4}317$	$0.0_{4}381$	$0.0_{4}510$	$0.0_{4}639$	$0.0_{3}128$

See Forsythe, J. Opt. Soc., 4,331, 1920, relative values, 0.4 to 0.76 μ (steps 0.01 μ), 12 temperatures, 1000 to 5000° K.

Table 310
BLACK-BODY SPECTRUM INTENSITIES
(J_λ), 25° to 600°K.

Values computed by editor using for C_1, 3.703×10^{-5} erg·cm²·sec.⁻¹, C_2 1.433 cm·°K, J_λ = tabular $J_\lambda \times 10^n$.

λ	25°K.		15°K.		75°K.		100°K.		150°K.		200°K.		250°K.		273°K.	
	J_λ	n	J_λ	n	J_λ	n	J_λ	n	J_λ	n	J_λ	n	J_λ	n	J_λ	n
1.0	3.7	−234	1.3	−109	4.1	−68	2.2	−47	1.2	−26	2.8	−16	4.7	−10	5.9	−8
1.5	4.9	−152	4.9	−69	2.3	−41	1.6	−27	1.1	−13	8.8	−7	1.23	−2	3.1	−1
2.0	3.9	−111	6.8	−49	3.8	−28	8.8	−18	2.1	−7	3.2	−2	4.2	1	4.6	2
2.5	9.9	−87	6.4	−37	2.4	−20	4.8	−12	9.6	−4	1.36	1	4.2	3	2.88	4
3.0	1.6	−70	5.0	−29	3.3	−15	2.7	−8	2.26	−1	6.5	2	7.7	4	3.84	5
3.5	5.1	−59	1.9	−23	1.4	−11	1.17	−5	9.8	0	9.1	3	5.4	5	2.16	6
4	2.1	−50	2.8	−19	6.5	−9	1.00	−3	1.54	2	6.0	4	2.16	6	7.2	6
5	1.9	−38	1.5	−13	3.0	−5	4.2	−1	5.9	3	7.1	5	1.25	7	3.26	7
6	1.6	−30	8.6	−10	7.1	−3	2.03	1	5.8	4	3.11	6	3.38	7	7.56	7
7	6.1	−25	3.7	−7	3.1	−1	2.84	2	2.60	5	7.87	6	6.13	7	1.22	8
8	8.6	−21	3.1	−5	4.8	0	1.88	3	7.4	5	1.46	7	8.75	7	1.60	8
9	1.4	−17	9.3	−4	3.8	1	7.6	3	1.55	6	2.19	7	1.08	8	1.84	8
10	4.7	−15	1.32	−2	1.87	2	2.21	4	2.63	6	2.87	7	1.20	8	**1.96**	8
12	2.7	−11	6.3	−1	1.81	3	9.7	4	5.20	6	3.81	7	**1.26**	8	1.90	8
14	1.1	−8	8.9	0	8.1	3	2.46	5	7.50	6	**4.15**	7	1.16	8	1.66	8
16	9.8	−7	5.9	1	2.30	4	4.56	5	9.02	6	4.06	7	1.01	8	1.38	8
18	2.90	−5	2.39	2	4.84	4	6.84	5	9.76	6	3.73	7	8.47	7	1.12	8
20	4.14	−4	6.9	2	8.2	4	8.95	5	**9.83**	6	3.31	7	6.99	7	9.04	7
25	4.18	−2	4.00	3	1.82	5	1.23	6	8.49	6	2.28	7	4.26	7	5.29	7
30	7.68	−1	1.08	4	2.62	5	**1.30**	6	6.58	6	1.52	7	2.65	7	3.21	7
40	2.16	1	2.80	4	**3.07**	5	1.04	6	3.62	6	7.24	6	1.13	7	1.33	7
50	1.25	2	**3.85**	4	2.65	5	7.15	5	2.06	6	3.71	6	5.52	6	6.38	6
75	7.5	2	3.50	4	1.32	5	2.71	5	6.06	5	9.77	5	1.36	6	1.54	6
100	1.20	3	2.24	4	6.43	4	1.16	5	2.32	5	3.54	5	4.78	5	5.37	5

λ	275°K.		300°K.		350°K.		373°K.		400°K.		500°K.		600°K.	
	J_λ	n	J_λ	n	J_λ	n	J_λ	n	J_λ	n	J_λ	n	J_λ	n
1.0	8.8	−8	6.7	−6	6.1	−3	7.6	−2	1.03	−1	1.32	3	1.58	5
1.5	4.0	−1	7.2	0	6.8	2	3.7	3	2.08	4	2.46	6	5.94	7
2.0	5.6	2	4.9	3	1.51	5	5.3	5	1.93	6	6.92	7	7.55	8
2.5	3.37	4	1.91	5	2.92	6	8.0	6	2.27	7	4.00	8	2.69	9
3.0	4.36	5	1.86	6	1.80	7	4.16	7	9.94	7	1.08	9	5.32	9
3.5	2.41	6	8.3	6	5.85	7	1.20	8	2.52	8	1.96	9	7.68	9
4	7.9	6	2.36	7	1.30	8	2.44	8	4.66	8	2.80	9	9.25	9
5	3.54	7	8.4	7	3.30	8	5.45	8	9.17	8	3.85	9	**1.01**	10
6	8.05	7	1.66	8	5.19	8	7.90	8	1.22	9	**4.04**	9	9.07	9
7	1.29	8	2.40	8	6.37	8	9.15	8	**1.33**	9	3.73	9	7.51	9
8	1.68	8	2.89	8	**6.81**	8	**9.36**	8	1.30	9	3.23	9	6.01	9
9	1.92	8	3.12	8	6.70	8	8.90	8	1.19	9	2.71	9	4.75	9
10	**2.03**	8	**3.14**	8	6.28	8	8.12	8	1.06	9	2.24	9	3.71	9
12	1.96	8	2.83	8	5.07	8	6.32	8	7.92	8	1.49	9	2.36	9
14	1.70	8	2.35	8	3.90	8	4.73	8	5.78	8	1.02	9	1.53	9
16	1.41	8	1.88	8	2.96	8	3.52	8	4.22	8	7.07	8	1.02	9
18	1.15	8	1.48	8	2.25	8	2.63	8	3.10	8	5.01	8	7.08	8
20	9.24	7	1.16	8	1.72	8	1.99	8	2.32	8	3.62	8	5.03	8
25	5.39	7	6.59	7	9.15	7	1.04	8	1.19	8	1.77	8	2.37	8
30	3.26	7	3.89	7	5.23	7	5.86	7	6.63	7	9.53	7	1.25	8
40	1.35	7	1.57	7	2.03	7	2.24	7	2.50	7	3.45	7	4.43	7
50	6.46	6	7.41	6	9.35	6	1.02	7	1.13	7	1.53	7	1.94	7
75	1.56	6	1.75	6	2.15	6	2.34	6	2.55	6	3.36	6	4.17	6
100	5.42	5	6.05	5	7.32	5	7.91	5	8.60	5	1.12	6	1.37	6

Table 311

BLACK-BODY SPECTRUM INTENSITIES

($J\lambda$), 800° to 25000°K.

(Same origin and data as Table 310.)

λ	800°K. Jλ	n	1000°K. Jλ	n	1200°K. Jλ	n	1400°K. Jλ	n	1600°K. Jλ	n	1800°K. Jλ	n	2000°K. Jλ	n	2200°K. Jλ	n
0.10	6	−58	2.1	−42	5.1	−32	1.3	−24	4.7	−19	1.0	−14	2.8	−11	1.9	−8
.20	1.5	−20	9	−13	1.4	−7	6.9	−4	4.1	−1	6.0	1	3.2	3	8.3	4
.30	1.8	−8	2.7	−3	7.9	0	2.3	3	1.65	5	4.5	6	6.5	7	5.7	8
.40	1.28	−2	1	2	3.9	4	2.8	6	6.8	7	8.2	8	6.0	9	3.08	10
.45	1.04	0	3	3	6.0	5	2.67	7	4.6	8	4.17	9	2.45	10	1.04	11
.50	3.3	1	4.2	4	5.0	6	1.53	8	1.97	9	1.44	10	7.1	10	2.60	11
.55	5.3	2	3.50	5	2.74	7	6.1	8	6.3	9	3.80	10	1.62	11	5.30	11
.60	5.2	3	2.02	6	1.08	8	1.86	9	1.56	10	8.2	10	3.10	11	9.2	11
.65	3.44	4	8.5	6	3.36	8	4.61	9	3.31	10	1.53	11	5.21	11	1.42	12
.70	1.69	5	2.84	7	8.6	8	9.9	9	6.1	10	2.53	11	7.91	11	2.00	12
.75	6.6	5	7.9	7	1.90	9	1.84	10	1.02	11	3.83	11	1.11	12	2.64	12
.80	2.13	6	1.88	8	3.71	9	3.14	10	1.55	11	5.39	11	1.46	12	3.29	12
.90	1.43	7	7.6	8	1.08	10	7.21	10	2.99	11	9.03	11	2.19	12	4.51	12
1.00	6.17	7	2.21	9	2.41	10	1.33	11	4.78	11	1.29	12	2.86	12	5.50	12
1.50	3.18	9	3.46	10	1.70	11	5.30	11	1.25	12	**2.43**	12	**4.15**	12	**6.44**	12
2.00	1.49	10	8.96	10	2.96	11	**6.98**	11	**1.33**	12	2.20	12	3.31	12	4.63	12
2.50	2.94	10	1.23	11	**3.22**	11	6.43	11	1.08	12	1.64	12	2.29	12	3.03	12
3.00	3.90	10	**1.29**	11	2.90	11	5.20	11	8.11	11	1.15	12	1.52	12	1.96	12
4.00	**4.16**	10	1.04	11	1.93	11	3.03	11	4.31	11	5.72	11	7.24	11	8.83	11
5.00	3.39	10	7.15	10	1.19	11	1.76	11	2.37	11	3.03	11	3.71	11	4.42	11
10.00	7.41	9	1.16	10	1.61	10	2.08	10	2.56	10	3.04	10	3.54	10	4.03	10
50.00																
100.00																

λ	4000°K. Jλ	n	5000°K. Jλ	n	6000°K. Jλ	n	8000°K. Jλ	n	10000°K. Jλ	n	15000°K. Jλ	n	20000°K. Jλ	n	25000°K. Jλ	n
0.10	1.02	5	1.32	8	1.57	10	6.2	12	2.21	14	2.63	16	2.86	17	1.20	18
.20	1.92	11	6.9	12	7.5	13	1.49	15	8.95	15	**9.84**	16	**3.31**	17	6.98	17
.30	9.9	12	1.08	14	5.32	14	3.90	15	**1.30**	16	6.58	16	1.52	17	2.64	17
.40	4.66	13	2.80	14	9.25	14	**4.16**	15	1.03	16	3.62	16	7.24	16	1.13	17
.45	7.00	13	3.45	14	9.98	14	3.82	15	8.67	15	2.73	16	5.13	16	7.79	16
.50	9.16	13	3.85	14	**1.00**	15	3.39	15	7.15	15	2.06	16	3.71	16	5.52	16
.55	1.09	14	4.04	14	9.72	14	2.95	15	5.87	15	1.57	16	2.74	16	4.00	16
.60	1.22	14	**4.05**	14	9.06	14	2.53	15	4.80	15	1.22	16	2.07	16	2.98	16
.65	1.30	14	3.93	14	8.31	14	2.16	15	3.96	15	9.53	15	1.58	16	2.26	16
.70	1.32	14	3.74	14	7.51	14	1.84	15	3.26	15	7.55	15	1.23	16	1.73	16
.75	**1.32**	14	3.49	14	6.74	14	1.56	15	2.71	15	6.06	15	9.76	15	1.36	16
.80	1.30	14	3.23	14	6.01	14	1.34	15	2.26	15	4.91	15	7.80	15	1.08	16
.90	1.19	14	2.71	14	4.75	14	9.93	14	1.60	15	3.32	15	5.15	15	7.04	15
1.00	1.06	14	2.23	14	3.70	14	7.41	14	1.16	15	2.32	15	3.54	15	4.78	15
1.50	4.88	13	8.47	13	1.24	14	2.12	14	3.04	14	5.48	14	7.96	14	1.04	15
2.00	2.32	13	3.62	13	5.03	13	7.99	13	1.10	14	1.88	14	2.68	14	3.48	14
2.50	1.18	13	1.76	13	2.37	13	3.62	13	4.90	13	8.15	13	1.14	14	1.47	14
3.00	6.63	12	9.53	12	1.25	13	1.86	13	2.48	13	4.06	13	5.65	13	7.24	13
4.00	2.50	12	3.45	12	4.42	12	6.40	12	8.40	12	1.34	13	1.84	13	2.34	13
5.00	1.13	12	1.53	12	1.93	12	2.75	12	3.57	12	5.62	12	7.70	12	9.76	12
10.00	8.60	10	1.12	11	1.37	11	1.88	11	2.40	11	3.66	11	4.98	11	6.28	11
50.00																
100.00																

TABLE 312.—Black Body Spectrum Intensities

Auxilliary table for J_λ at any temperature (Menzel, Harvard Observatory)

Let J_0 = intensity for T_0 = 10,000° K.; for another temperature T° K., we have the relationship

$$J/J_0 = \left[\lambda^5_0\left(e^{c_2/\lambda_0 T_0} - 1\right)\right]/\left[\lambda^5\left(e^{c_2/\lambda T} - 1\right)\right].$$

Let $\lambda = \lambda_0 T_0/T$. Then $J_0\,(T/T_0)^5$. e. g., to find J_λ for 0.5μ, 6000°K., we take 0.5μ = $\lambda_0 \times$ 10,000/6,000 or λ_0 = 0.3μ, J_0 for 0.3μ = 1.2977×10^{16}, whence $J = 1.2977 \times 10^{16} \times (6000/10000)^5$ or 1.01×10^{15}.

In the following table J_λ is for 10,000° K.; $J_\lambda \times 10^n$ is intensity at wave length $\lambda\mu$. λ is given in μ but in plotting it should be used in cm (one $\mu = 10^{-4}$ cm) that the area under curve be in ergs.

hc/k = 1.43187; $2\pi hc^2$ = 3.69728 c.g.s. units. A change in c_1 may be allowed for by a constant factor, in c_2 by taking a different value for T so that $1.4319 \times 10{,}000 = c_2T$. One erg·cm·$^{-2}$·sec.$^{-1}$ = 2.389×10^{-8} cal.$_{15}$· cm^{-2}· sec^{-1}.

λ	J_λ (ergs)	n	λ	J_λ (ergs)	n	λ	J_λ (ergs)	n	λ	J_λ (ergs)	n
μ			μ			μ			μ		
.0100	2.4131	−37	.1450	2.9673	15	.5500	5.8731	15	4.500	5.3480	12
.0150	4.7932	−26	.1500	3.4824	15	.6000	4.8153	15	5.000	3.5680	12
.0200	9.3330	− 1	.1600	4.5367	15	.6500	3.9579	15	6.000	1.7645	12
.0250	5.0592	− 1	.1700	5.7244	15	.7000	3.2677	15	7.000	9.6897	11
.0300	2.8437	2	.1800	6.8702	15	.7500	2.7735	15	8.000	5.7562	11
.0350	1.2032	5	.1900	7.9697	15	.8000	2.2620	15	9.000	3.6298	11
.0400	1.0261	7	.2000	8.9902	15	.8500	1.9165	15	10.00	2.4018	11
.0450	3.0403	8	.2100	9.9098	15	.9000	1.6018	15	12.00	1.1727	11
.0500	4.3245	9	.2200	1.0711	16	.9500	1.3596	15	14.00	6.3824	10
.0550	3.6280	10	.2300	1.1387	16	1.0000	1.1601	15	16.00	3.7652	10
.0600	2.0556	11	.2400	1.1938	16	1.1000	8.5810	14	18.00	2.3634	10
.0650	8.6361	11	.2500	1.2365	16	1.2000	6.4670	14	20.00	1.5569	10
.0700	2.8766	12	.2600	1.2680	16	1.3000	4.9587	14	25.00	6.4241	9
.0750	7.9649	12	.2700	1.2883	16	1.4000	3.8600	14	30.00	3.1121	9
.0800	1.9021	13	.2800	1.2996	16	1.5000	3.0472	14	35.00	1.6858	9
.0850	4.0261	13	.2900	1.3023	16	1.6000	2.2038	14	40.00	9.9057	8
.0900	7.7120	13	.3000	1.2977	16	1.7000	1.9702	14	45.00	6.1974	8
.0950	1.3598	14	.3200	1.2700	16	1.8000	1.6096	14	50.00	4.0718	8
.1000	2.2355	14	.3400	1.2246	16	1.9000	1.3276	14	55.00	2.7860	8
.1050	3.4637	14	.3600	1.1673	16	2.0000	1.1046	14	60.00	1.9697	8
.1100	5.1028	14	.3800	1.1031	16	2.200	7.8206	13	65.00	1.3983	8
.1150	7.1944	14	.4000	1.0358	16	2.400	5.6907	13	70.00	1.0643	8
.1200	9.7255	14	.4200	9.9002	15	2.600	4.2361	13	80.00	6.2476	7
.1250	1.2839	15	.4400	9.0036	15	2.800	3.2185	13	90.00	3.9036	7
.1300	1.6394	15	.4600	8.3551	15	3.000	2.6973	13	100.00	2.5640	7
.1350	2.0414	15	.4800	7.7401	15	3.500	1.3927	13			
.1400	2.4858	15	.5000	7.1589	15	4.000	8.3888	12			

TABLE 313.—Values of J_λ for Various Temperatures Centigrade

Ekholm, Met. Z. 1902, used $C_1 = 8346$ and $C_2 = 14349$, and for the unit of time the day.
For 100°, the values for Jλ have been multiplied by 10, for the other temperatures by 100.

λ	T= 100° C	30° C	15° C	0° C	−30° C	−80° C	λ	100° C	30° C	15° C	0° C	−30° C	−80° C
μ							μ						
2	1	0	0	0	0	0	18	511	2961	2557	2175	1491	623
3	80	41	18	7	1	0	19	443	2626	2281	1954	1363	594
4	469	508	272	138	27	1	20	386	2329	2034	1754	1242	561
5	1047	1777	1085	628	172	8	21	337	2068	1816	1574	1129	527
6	1526	3464	2296	1454	493	39	22	295	1840	1622	1413	1026	494
7	1768	4954	3481	2353	931	105	23	259	1639	1448	1270	931	460
8	1810	5928	4352	3088	1372	203	24	228	1462	1298	1141	846	428
9	1724	6382	4834	3646	1730	316	25	202	1307	1165	1028	768	398
10	1573	6386	4979	3781	1971	426	26	179	1170	1047	926	698	369
11	1398	6127	4833	3798	2098	520	28	142	947	850	757	579	317
12	1225	5712	4633	3676	2114	592	30	114	771	696	623	482	272
13	1063	5222	4300	3467	2090	640	40	44	311	285	259	209	130
14	918	4713	3930	3215	2004	666	50	20	146	135	124	102	67
15	792	4220	3556	2944	1889	673	60	10	77	72	66	55	38
16	683	3759	3198	2674	1760	663	80	4	27	25	24	20	14
17	590	3340	2862	2417	1626	649	100	2	12	11	10	9	7

SPECTRAL ENERGY DISTRIBUTION AND LUMINOSITY DATA

For use in computing light transmissions and relative brightnesses from spectrometric data. Range of color temperatures 2000°K. to 3000°K. Considerably abridged from Skogland, Bur. Standards, Misc. Publ., No. 86; see also No. 56, 1925, range, 1000° to 28000°K. Planck's formula used with C_2, 14330μ deg. The constant of Wien's displacement law has been determined as 2886.3μ deg.

TABLE 314.—Relative J_λ, based on J at $\lambda = 0.59\mu$ or 590 mμ

EXAMPLE: At color temperature 2296°K. and λ, 0.65μ, the energy radiated relative to that at 0.59μ is 1.6361.

λ in μ	2000°K.	2100°K.	2200°K.	2300°K.	2400°K.	2500°K.	2600°K.	2700°K.	2800°K.	2900°K.	3000°K.
.32	0.0007	0.0012	0.0019	0.0029	0.0042	0.0059	0.0080	0.0108	0.0141	0.0182	0.0230
.34	21	31	47	67	92	.0124	.0164	211	267	333	409
.36	50	73	.0102	.0139	.0184	239	303	378	463	561	669
.38	.0110	.0151	203	264	336	420	517	626	747	882	.1029
.40	218	287	369	463	571	691	826	973	.1134	.1306	.1492
.42	402	507	628	762	910	.1073	.1248	.1435	.1634	.1844	.2060
.44	690	841	.1006	.1185	.1376	.1580	.1794	.2019	.2252	.2494	.2743
.46	.1122	.1321	.1533	.1755	.1988	.2228	.2477	.2731	.2991	.3254	.3520
.48	.1735	.1981	.2235	.2494	.2760	.3028	.3298	.3570	.3843	.4116	.4388
.50	.2571	.2852	.3136	.3420	.3701	.3981	.4257	.4531	.4800	.5066	.5326
.52	.3667	.3964	.4254	.4538	.4815	.5085	.5347	.5602	.5849	.6090	.6322
.54	.5058	.5336	.5602	.5856	.6100	.6333	.6556	.6739	.6973	.7170	.7356
.56	.6773	.6986	.7186	.7373	.7549	.7714	.7871	.8017	.8156	.8289	.8413
.58	.8835	.8923	.9006	.9080	.9148	.9213	.9272	.9327	.9379	.9428	.9473
.59	.00007	.00013	.0002	.0004	.0006	.0008	.0012	.0017	.0024	.0032	.0043
.60	1.1256	1.1148	1.1051	1.0963	1.0885	1.0810	1.0743	1.0681	1.0624	1.0571	.0523
.62	1.4044	1.3657	1.3314	1.3009	1.2734	1.2486	1.2263	1.2060	1.1875	1.1704	1.1549
.64	1.7195	1.6435	1.5773	1.5193	1.4680	1.4223	1.3815	1.3449	1.3114	1.2812	1.2537
.66	2.0698	1.9468	1.8410	1.7498	1.6699	1.5998	1.5378	1.4824	1.4329	1.3882	1.3479
.68	2.4534	2.2727	2.1199	1.9895	1.8770	1.7792	1.6934	1.6177	1.5505	1.4905	1.4366
.70	2.8679	2.6189	2.4110	2.2361	2.0869	1.9584	1.8468	1.7493	1.6633	1.5872	1.5193
.72	3.310	2.7986	2.7120	2.4872	2.2972	2.1357	1.9965	1.8757	1.7704	1.6776	1.5955
.74	3.777	3.360	3.020	2.7403	2.5068	2.3095	2.1413	1.9966	1.8710	1.7614	1.6648
.76	4.265	3.748	3.332	2.9931	2.7126	2.4786	2.2801	2.1105	1.9647	1.8380	1.7272

TABLE 315.—Luminosity Relative to Maximum Value at Each Temperature

EXAMPLE: At color temperature 2680°K. and $\lambda = 0.55\mu$, the luminosity relative to that at 0.5720μ is 0.8874.

λ in μ	2000°K.	2200°K.	2400°K.	2600°K.	2800°K.	3000°K.	Equal energy = visibility
0.40	.0000	.0000	.0000	.0000	.0001	.0001	.0004
.42	.0002	.0003	.0005	.0006	.0008	.0010	.004
.44	.0021	.0029	.0040	.0050	.0062	.0074	.023
.46	.0087	.0123	.0149	.0182	.0215	.0248	.060
.48	.0314	.0397	.0480	.0561	.0640	.0716	.139
0.50	.1079	.1292	.1495	.1683	.1859	.2021	.323
.52	.3383	.3853	.4274	.4645	.4977	.5269	.710
.54	.6270	.6816	.7275	.7655	.7972	.8239	.954
.56	.8758	.9120	.9390	.9584	.9726	.9826	**.995**
.58	**.9988**	**.9994**	**.9950**	**.9873**	**.9780**	**.9676**	.870
0.60	.9231	.8897	.8585	.8299	.8035	.7796	.631
.62	.6954	.6473	.6066	.5722	.5422	.5166	.381
.64	.3910	.3524	.3212	.2960	.2751	.2576	.175
.66	.1641	.1433	.1273	.1148	.1048	.0966	.061
.68	.0542	.0460	.0399	.0352	.0316	.0287	.017
0.70	.0153	.0126	.0107	.0093	.0082	.0073	.0041
2	.0045	.0035	.0030	.0026	.0022	.0020	.0010
4	.0012	.0010	.0008	.0007	.0006	.0005	.0002
6	.0003	.0003	.0002	.0002	.0001	.0001	.0001
Sum	10.464	10.503	10.535	10.556	10.572	10.581	10.686
Max. at	.5818μ	.5788	.5758	.5730	.5705	.5682	.555

SPECTRAL ENERGY DISTRIBUTION AND LUMINOSITY DATA (*concluded*)

Factors proportional to the values of Table 315 adjusted so that the area of each complete curve of minosity factors between 0.40 and 0.76μ is equal to unity. To obtain the light transmission of a screen, ultiply the spectrum transmission at each λ by the corresponding tabulated or interpolated factor, otaining in each case an element of light transmission for the wave-length interval $\lambda - .01\mu$ to $\lambda + .01\mu$. he integral light transmission is obtained as the sum of these elements. The same process is followed r spectrum reflection.

TABLE 316.—Luminosity Factors

λ in μ	2000°K.	2100°K.	2200°K.	2300°K.	2400°K.	2500°K.	2600°K.	2700°K.	2800°K.	2900°K.	3000°K.
0.40	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
.42	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0001	.0001	.0001	.0001
.44	.0002	.0002	.0003	.0003	.0004	.0004	.0005	.0005	.0006	.0007	.0007
.46	.0008	.0010	.0011	.0012	.0014	.0016	.0017	.0019	.0020	.0021	.0023
.48	.0030	.0034	.0038	.0042	.0046	.0049	.0052	.0056	.0061	.0064	.0067
.50	.0103	.0114	.0123	.0133	.0142	.0151	.0160	.0168	.0176	.0184	.0191
.52	.0323	.0347	.0367	.0386	.0406	.0424	.0440	.0455	.0471	.0486	.0498
.54	.0599	.0627	.0649	.0669	.0690	.0710	.0725	.0740	.0754	.0768	.0779
.56	.0837	.0855	.0868	.0880	.0891	.0901	.0908	.0914	.0920	.0925	.0929
.58	.0954	.0954	.0954	.0949	.0944	.0939	.0935	.0930	.0925	.0919	.0914
.60	.0882	.0863	.0847	.0832	.0815	.0799	.0786	.0773	.0760	.0747	.0737
.62	.0664	.0638	.0616	.0596	.0576	.0558	.0542	.0527	.0513	.0499	.0488
.64	.0374	.0352	.0335	.0320	.0305	.0292	.0280	.0270	.0260	.0251	.0243
.66	.0157	.0145	.0136	.0129	.0121	.0115	.0109	.0104	.0099	.0095	.0091
.68	.0052	.0047	.0044	.0041	.0038	.0035	.0033	.0032	.0030	.0028	.0027
.70	.0015	.0013	.0012	.0011	.0010	.0009	.0009	.0008	.0008	.0007	.0007
.72	.0004	.0004	.0003	.0003	.0003	.0003	.0002	.0002	.0002	.0002	.0002
.74	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0000	.0000
.76	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
Max. value	.0956	.0953	.0952	.0950	.0949	.0948	.0947	.0947	.0946	.0945	.0945
Max. at μ =	.5818	.5802	.5788	.5774	.5758	.5743	.5730	.5718	.5705	.5693	.5683
Cantroid μ =	.5830	.5814	.5800	.5786	.5770	.5757	.5742	.5730	.5717	.5705	.5695

TABLE 317.—Percentage Change in J for Change of $\pm$ 30 in Planck's C_2 (14330)

EXAMPLE: At color temperature 2300°K., the value below for 0.44μ is 0.8%, due to a change of 30 in C_2. For a change of 20 in C_2 the change in $J_{0.44}$ is ⅔ of 0.8 = 0.5%; for a change of 15 in C_2, ½ of 0.8 = 0.4%, etc.

Algebraic sign of tabulated values:

	Tabulated values 1st 6 col.	Next 6 col.
Change in C_2—Increase	−	+
Decrease	+	−

In line "all λ" are given values for adjustment of the percentage values above in Table 315 to obtain he % change in the luminosity factors of Table 316. Each of these constants applies to all values given bove it in the table; that is, one constant for each temperature. Combine the given constant by algebraic ddition with the individual values at each wave length.

EXAMPLE: Color temp. 2600° K.; λ = 0.52μ; C_2 changed from 14330 to 14310. At 0.52μ, 2600°K., 0.3% s tabulated. Its sign is +, and C_2 is decreased. The corresponding constant in line "all λ" is −0.07, the ninus sign corresponding to a decrease in C_2. For a change of −30 in C_2, the % change for Table 317 is .3−0.1%. For the assigned change of −20 in C_2, the required adjustment to the value in Table 316 is ⅔ f 0.2 = 0.1%. At λ = .71μ, the adjustment would be ⅔ (−0.3 − 0.1) = − 0.2%, etc.

λ in μ	2000°K.	2300°K.	2600°K.	2900°K.	3200°K.	λ in μ	2000°K.	2300°K.	2600°K.	2900°K.	3200°K.
0.32	2.0%	1.9%	1.7%	1.5%	1.3%	0.60	....	....	....	....	....
.34	1.8	1.6	1.5	1.3	1.1	.62	....	....	0.1	0.1	0.1
.36	1.6	1.4	1.3	1.1	1.0	.64	....	0.2	.2	....	....
.38	1.4	1.2	1.1	.9	.9	.66	0.3	....	....	.2	.2
						.68	.3	.3	.3	.2	.2
.40	1.2	1.0	.9	.8	.8						
.42	1.0	.9	.8	.7	.7	.70	.4	.3	.3	.3	.2
.44	.9	.8	.7	.6	.6	.72	.4	.4	.4	.3	.3
.46	.7	.6	.5	.5	.5	.74	.5	.4	.4	.4	.3
.48	.6	.5	.4	.4	.4	.76	.6	.5	.4	.4	.4
.50	.5	.4	.4	.3	.3	all λ	.04	.06	.07	.07	.07
.52	.3	.3	.3	.2	.2						
.54	.2	.2	.2	.2	.2						
.56	.1	.1	.1	.1	.1						
.58	.0	.0	.0	.0	.0						

RADIATION EMISSIVITIES

TABLE 318.—Relative Emissive Powers for Total Radiation

Emissive power of black body = 1. Receiving surface platinum black at 25° C; oxidized surfaces oxidized at 600 + ° C. Randolph and Overholzer, Phys. Review, 2, p. 144, 1913.

	Temperature, Deg. C 200	400	600
Silver	0.020	0.030	0.038
Platinum (1)	0.060	0.086	0.110
Oxidized zinc	—	0.110	—
Oxidized aluminum	0.113	0.153	0.192
Calorized copper, oxidized	0.180	0.185	0.190
Cast iron	0.210	—	—
Oxidized nickel	0.369	0.424	0.478
Oxidized monel	0.411	0.439	0.463
Calorized steel, oxidized	0.521	0.547	0.570
Oxidized copper	0.568	0.568	0.568
Oxidized brass	0.610	0.600	0.589
Oxidized lead	0.631	—	—
Oxidized cast iron	0.643	0.710	0.777
Oxidized steel	0.790	0.788	0.787
Black body	1.00	1.00	1.00

Remark: For radiation properties of bodies at temperatures so low that the radiations of wave length greater than 20μ or thereabouts are important, doubt must exist because of the possible and perhaps probable lack of blackness of the receiving body to radiations of those wave lengths or greater. For instance, see Tables 455 and 460 for the transparency of soot.

TABLE 319.—Emissivities of Metals and Oxides

Emissivities for radiation of wave-length 0.55 and 0.65 μ. Burgess and Waltenberg, Bul. Bureau of Standards, 11, 591, 1914.

In the solid state practically all the metals examined appear to have a negligible or very small temperature coefficient of emission for $\lambda = 0.55$ and $0.65\ \mu$ within the temperature range 20° C to melting point. Nickel oxide has a well-defined negative coefficient, at least to the melting point. There is a discontinuity in emissivity, for $\lambda = 0.65\ \mu$ at the melting point for some but not all the metals and oxides. This effect is most marked for gold, copper, and silver, and is appreciable for platinum and palladium. Palladium, in addition, possesses for radiation a property analogous to suffusion, in that the value of emissivity ($\lambda = 0.65\ \mu$) natural to the liquid state may persist for a time after solidification of the metal. The Violle unit of light does not appear to define a constant standard. Article contains bibliography.

Metals	Cu	Ag	Au	Pd	Pt	Ir	Rh	Ni	Co	Fe	Mn	Ti
e_λ, 0.55 μ solid	0.38	0.35	0.38	0.38	0.38	—	0.29	0.44	—	—	—	0.75
0.55 μ liquid	0.36	0.35	0.38	—	—	—	—	0.46	—	—	—	0.75
0.65 μ solid	0.10	0.04	0.14	0.33	0.33	0.30	0.29	0.36	0.36	0.37	0.59	0.63
liquid	0.15	0.07	0.22	0.37	0.38	—	0.30	0.37	0.37	0.37	0.59	0.65
Metals	**Zr**	**Th**	**Y**	**Er**	**Be**	**Cb**	**V**	**Cr**	**Mo**	**W**	**U**	
e_λ, 0.55 μ solid	—	0.36	—	—	0.61	0.61	0.29	0.53	—	—	0.77	
liquid	—	—	—	0.30	0.81	—	—	—	—	—	—	
0.65 μ solid	0.32	0.36	0.35	0.55	0.61	0.49	0.35	0.39	0.43	0.39	0.54	
liquid	0.30	0.40	0.35	0.38	0.61	0.40	0.32	0.39	0.40	—	0.34	
Oxides: 0.65 μ	**NiO**	**Co_3O_4**	**Fe_3O_4**	**Mn_3O_4**	**TiO_2**	**ThO_2**	**Y_2O_3**	**BeO**	**CbO_x**	**V_2O_3**	**Cr_2O_3**	**U_3C_8**
e_λ, solid	0.89	0.77	0.63	—	0.52	0.57	0.61	0.37	0.71	0.69	0.60	0.30
liquid	0.68	0.63	0.53	0.47	0.51	0.69	—	—	—	—	—	0.31

Table 320

SOME INTRINSIC PROPERTIES OF TUNGSTEN

(Jones, Langmuir, Gen. Electr. Rev., July-August, 1927)

T°K.	Resistivity $\rho \times 10^6$ ohm.cm	Power radiated W watts/cm²	Brightness B int. cand./cm²	Efficiency E	Electron emission $i \times 10^n$ i	n	Evaporation $M \times 10^n$ M	n	Vapor pressure p baryes $\times 10^n$ p	n	Power emissivity black body = 1	Thermal expansion in per cent l_0 at 293°	Atomic heat cal./g-atom./°C	Heat content cal·10⁻² / g·atom
					amp./cm²		g/cm² sec.		dynes/cm²					
300	5.65	3×10^{-5}									.017	.003	6.0	12
400	8.06	2×10^{-3}									.024	.044	6.0	18
500	10.56	1×10^{-2}									.032	.086	6.1	24
600	13.23	.030									.043	.130	6.1	30
700	16.09	.076									.057	.175	6.2	36
800	19.00	.169									.072	.222	6.2	42
900	21.94	.322									.088	.270	6.3	48
					i	n	M	n	P	n				
1000	24.93	.602	1×10^{-4}	17.3	1.07	−15	5.32	−34	1.98	−29	.105	.320	6.4	54
1100	27.94	1.027	1×10^{-3}	15.6	1.52	−13	2.17	−30	1.22	−25	.124	.371	6.4	60
1200	30.98	1.66	6×10^{-3}	14.2	9.73	−12	3.21	−27	1.87	−22	.141	.424	6.5	66
1300	34.08	2.57	3×10^{-2}	13.1	3.21	−10	1.35	−24	8.18	−20	.158	.479	6.7	75
1400	37.19	3.83	1×10^{-1}	12.0	6.62	−9	2.51	−22	1.62	−17	.175	.535	6.8	82
1500	40.36	5.52	0.33	11.1	9.14	−8	2.37	−20	1.54	−15	.192	.593	7.0	89
1600	43.55	7.74	0.93	10.3	9.27	−7	1.25	−18	8.43	−14	.207	.652	7.1	96
1700	46.78	10.62	2.33	9.5	7.08	−6	4.17	−17	2.82	−12	.222	.713	7.2	103
1800	50.05	14.19	5.12	8.8	4.47	−5	8.81	−16	6.31	−11	.237	.775	7.4	110
1900	53.35	18.64	10.93	8.2	2.28	−4	1.41	−14	1.01	−9	.250	.839	7.6	118
2000	56.67	24.04	20.66	7.6	1.00	−3	1.76	−13	1.33	−8	.263	.904	7.7	125
2100	60.06	30.5	37.75	7.1	3.93	−3	1.66	−12	1.28	−7	.274	.971	7.8	133
2200	63.48	38.2	64.0	6.7	1.33	−2	1.25	−11	9.88	−7	.285	1.039	8.0	141
2300	66.91	47.2	103.7	6.2	4.07	−2	8.00	−11	6.47	−6	.295	1.109	8.2	149
2400	70.39	57.7	164.4	5.8	1.16	−1	4.26	−10	3.52	−5	.304	1.180	8.3	157
2500	73.91	69.8	248	5.5	2.98	−1	2.03	−9	1.71	−4	.312	1.253	8.4	166
2600	77.49	83.8	364	5.1	7.16	−1	8.41	−9	7.24	−4	.320	1.328	8.6	174
2700	81.04	99.6	532	4.8	1.63	0	3.19	−8	2.86	−3	.327	1.404	8.7	183
2800	84.70	117.6	732	4.5	3.54	0	1.10	−7	9.84	−3	.334	1.479	8.9	192
2900	88.33	137.8	987	4.2	7.31	0	3.30	−7	3.00	−2	.340	1.561	9.0	201
3000	92.04	160.5	1326	4.0	1.42	+1	9.95	−7	9.20	−2	.346	1.642	9.2	210
3100	95.76	185.8	1745	3.7	2.64	+1	2.60	−6	2.50	−1	.352	1.724	9.4	219
3200	99.54	214.0	2252	3.5	4.78	+1	6.38	−6	6.13	−1	.357	1.808	9.5	228
3300	103.3	245.4	2893	3.3	8.44	+1	1.56	−5	1.51	0	.362	1.893	9.6	238
3400	107.2	280.0	3660	3.1	1.42	+2	3.47	−5	3.41	0	.366	1.980	9.8	248
3500	111.1	318.0	4540	2.9	2.33	+2	7.54	−5	7.52	0	.370	2.068	9.9	258
3600	115.0	360.0	5530	2.8	3.73	+2	1.51	−4	1.53	1	.374	2.158	10.1	268
3655	117.1	382.6	6163	2.7	4.79	+2	2.28	−4	2.33	1	.376	2.209	10.2	273

TABLE 321.—Spectrum Emissivity of Tungsten (Percentage)

Weniger and Pfund (Phys. Rev., 14, 427, 1919) verified Drude's formula for tungsten, $100 - R_\lambda = e_\lambda = 3650 \sqrt{\rho/\lambda}$, valid for $\lambda > 2\mu$, where R_λ = reflectivity, λ, the wave length in μ, ρ, the specific resistance at the temperature considered. The following u.v. data is from Hulburt (Astrophys. Journ. 45, 149, 1917, via Forsythe, Christison, Gen. Electr. Rev., p. 622, 1929), from which the data for 0.2 to 4.2μ, 2800° are taken.

	0.34μ	0.38μ	0.42μ	0.48μ	0.50μ	0.54μ					
1800	49.3	49.2	48.8	48.0	46.0	44.2					
2200	48.7	48.5	47.8	46.7	45.0	43.0					
2600	48.3	48.0	47.2	46.0	44.2	42.1					
3000	48.0	47.7	46.8	45.4	43.5	41.4					
3400	47.7	47.4	46.5	44.8	42.7	40.7					
	0.2μ	0.6	1.0	1.4	1.8	2.2	2.6	3.0	3.4	3.8	4.2μ
2800°	51	43	36	30	26	23	21	19	18	17	17

TABLE 322.—Temperature Scale for Tungsten

Hyde, Cady, Forsythe, Journ. Franklin Inst. 181, 418, 1916. See also Phys. Rev. 10,395, 1917. The color temperature = temperature of black body at which its color matches the given radiation.

Lumens/watt	Color temperature	Black-body temperature	True temperature	True temperature	True–color	True–brightness
1	1763°K.	1627°K.	1729°K.	1700°	12°	100°
2	1917	1753	1875	1800	20	115
3	2025	1840	1976	1900	26	128
4	2109	1909	2056	2000	31	142
5	2179	1967	2125	2100	36	158
6	2237	2017	2184	2200	39	175
7	2290	2062	2238	2300	41	191
8	2338	2102	2286	2400	43	208
9	2383	2140	2332	....	..	...
10	2425	2174	2373	....	..	...

TABLE 323.—Radiation Characteristics of Tungsten

(Forsythe, Worthing, Astrophys. Journ., 61, 146, 1925.)

Temp. °K.	Emissivity				Temperature °K.		
	0.665μ	0.467μ	Average luminous	Color	Brightness 0.665μ	Color	Radiation
500	0.466	0.498	....	....	...	....	....
1000	.456	.486	0.464	0.396	966	1006	581
1500	.445	.476	.457	.383	1420	1517	991
2000	.435	.469	.452	.370	1857	2033	1428
2500	.425	.462	.446	.356	2274	2557	1859
3000	.415	.455	.440	.343	2673	3094	2286
3500	(.405)	(.449)	(.434)	(.329)	3053	(3646)	(2704)

TABLE 324.—Radiation and Other Properties of Tantalum

(Worthing, Phys. Rev., 28, 190, 1926.)

°K.	Emissivity .665μ	Emissivity .463μ	Temperature Brightness .665μ °K.	Temperature Color °K.	Temperature Radiation °K.	Resistivity μ-ohm-cm	Radiation Watt/cm²	$\frac{Tdn}{ndT}$	Total emissivity
300	0.493	0.56	....	....	....	....	....	....	....
1000	.459	.52	966	....	....	....	....	....	....
1200	.450	.51	1149	....	....	....	....	....	....
1400	.442	.50	1329	....	....	....	....	....	....
1600	.434	.49	1506	1642	1062	67.6	7.3	4.80	0.194
1800	.426	.48	1680	1859	1222	74.1	12.8	4.80	.213
2000	.418	.47	1851	2075	1390	80.5	21.2	4.80	.232
2200	.411	.46	2018	2288	1556	86.9	33.4	4.80	.251
2400	.404	.45	2180	2497	1730	92.9	50.7	4.80	.269
2600	.397	.44	2339	2705	1901	99.1	75	4.80	.287
2800	.390	..	2495	2911	2080	105.0	106	4.80	.304
3000	.384	..	2647	....	....	....	....	....	....
3300 mp	.375	..	2870	....	....	....	....	....	....

TABLE 325.—Radiation and Other Properties of Molybdenum

(Worthing, Phys. Rev., 28, 190, 1926.)

°K.	Emissivity .665μ	Emissivity .475μ	Temperature Brightness $S_{.665\mu}$ °K.	Temperature Color °K.	Temperature Radiation °K.	Resistivity μ-ohm-cm	Brighness normally candles/cm²	Radiation intensity watts/cm²	Luminous efficiency lumens/watt
273	0.420	0.425	....	....	....	5.14	....	....	....
1000	.390	.403	958	1004	557	23.9	0.0001	0.55	....
1400	.375	.393	1316	1411	864	35.2	.089	3.18	0.093
1600	.367	.388	1489	1616	1024	41.1	.765	6.30	.40
1800	.360	.383	1658	1823	1187	47.0	4.13	11.3	1.22
2000	.353	.379	1824	2032	1354	53.1	15.9	19.2	2.75
2200	.347	.375	1986	2244	1523	59.2	48.5	30.7	5.28
2400	.341	.371	2143	2456	1693	65.5	123	47.0	8.70
2600	.336	.368	2297	2672	1866	71.8	270	69.5	13.0
2800	.331	.365	2448	2891	2039	78.2	540	98	18.4
2895	.328	.363	2519	2997	2122	81.4	730	116	....

TABLE 326.—Relation between Brightness Temperature and Color Temperature for Various Substances

Brightness temperature	Corresponding color temperature for— Untreated carbon	Gem	Platinum	Nernst glower	Osmium	Tantalum	Tungsten
1400°K.	1414	....	1568°K.	1538	1444	1507	1492
1500	1515	....	1692	1642	1562	1631	1607
1600	1616	1620	1821	1747	1680	1758	1723
1700	1718	1735	1952	1852	1799	1883	1841
1800	1820	1852	2086	1954	1919	2010	1961
1900	1923	1962	....	2053	2045	2137	2082
2000	2028	2064	....	2146	2168	2265	2206
2200	2240	2255	....	2310	2427	2500	2457
2400	....	....	....	....	2688	2785	2718
2600	....	....	....	....	....	....	2988
3000	....	....	....	....	....	....	3564

TABLE 327.—Color Minus Brightness Temperature for Carbon

(Hyde, Cady, Forsythe, Phys. Rev. 10, 395, 1917.)

Brightness temp. °K.....	1600°	1700°	1800°	1900°	2000°	2100°	2200°
Color—brightness.......	2	7	12	16	22	28	33

TABLE 328.—Percentage Emissivities of Metals and Oxides

Emissivity of black body taken as 100

True temperature C.	500°	600°	700°	800°	900°	1000°	1100°	1200°	Ref.
60 FeO.40 Fe_2O_3 = Fe heated in air .... Total	85	85	86	87	87	88	88	89	1
$\lambda = 0.65\ \mu$	—	—	—	98	97	95	93	92	1
NiO .... Total	—	54	62	68	72	75	81	86	2
.... $\lambda = 0.65\ \mu$	—	—	98	96	94	92	88	87	2

Platinum:													
True temp. C......	0	100	200	300	400	500	750	1000	1200	1400	1600	1700	3
App.* temp. C.....	—	—	—	—	—	—	—	486	630	780	930	1005	3
Total emiss. Pt.....	3.1	4.0	5.1	6.1	7.0	8.0	10.3	12.4	14.0	15.5	16.9	17.5	3

Tungsten:											
True temp. K (abs.).......	200	600	1000	1400	1800	2200	2600	3000	3400	3800	4
$\lambda = 0.467$............	51.8	50.8	49.8	48.9	47.9	47.0	46.0	45.0	44.1	—	4
$\lambda = 0.665$............	48.2	47.2	46.3	45.3	44.3	43.3	42.4	41.4	40.4	39.5	4

* As observed with total radiation pyrometer sighted on the platinum.
References: (1) Burgess and Foote, Bul. Bureau of Standards, 12, 83, 1915; (2) Burgess and Foote, *loc. cit.* 11, 41, 1914; (3) Foote, *loc. cit.* 11, 607, 1914; (4) Worthing, Phys. Rev. 10, 377, 1917.

TABLE 329.—Emissivities, Metals (Black body = 1)

(Worthing, Phys. Rev., 28, 174, 1926.)

	t°C	0.460μ	0.535μ	0.665μ	T°K.	0.460μ	0.535μ	0.665μ
Gold............	20	0.635	0.352	0.062	1275..............	0.632	0.448	0.140
Nickel...........	"	.45	....	.375	1200–1650..........	.45	.425	.375
Tantalum........	"	....	....	.48	1400..............	....	....	.442
					2100..............	....	....	.415
					2800..............	....	....	.390

Platinum	0.665	1100°K. 0.292	1300° 0.297	1500° 0.302	1700° 0.307	1900° 0.312
	.463			1500° .370	1700° .381	1900° .392

Total radiation = C′T^n watt/cm², nichrome values poor. Suydam, Phys. Rev., 5, 497, 1915.

	Ag 610°–980°K.	Pt 640°–1150°K.	Ni 463°–1280°K.	Fe 700°–1300°K.	Nichrome 325°–1310°K.
C′	3.0×10^{-13}	2.3×10^{-15}	1.0×10^{-14}	3.2×10^{-17}	1.8×10^{-12}
n	4.1	5.0	4.65	5.55	4.1

Specific values are given in this paper for various temperatures of both radiator and absorber. Also for electrical resistances.

TABLE 330.—Total Radiation from Bare and Soot-Covered Nickel (Watts/cm²)

(Barnes, Phys. Rev., 34, 1026, 1929.)

°K.	400	500	600	700	800	900	1000	1200	1400
Soot-covered Ni..........	0.096	0.28	0.59	1.87	3	3	4.8	....	....
Polished Ni initial heat....	.0092	.032	.079	.166	.31	.55	.91	2.17	4.49
" " after above....	.0066	.023	.058	.123	.24	.44	.76	2.04	4.49

COOLING BY RADIATION AND CONVECTION

TABLE 331.—At Ordinary Pressures

According to McFarlane * the rate of loss of heat by a sphere placed in the centre of a spherical enclosure which has a blackened surface, and is kept at a constant temperature of about 14° C, can be expressed by the equations

$$e = .000238 + 3.06 \times 10^{-6}t - 2.6 \times 10^{-8}t^2,$$

when the surface of the sphere is blackened, or

$$e = .000168 + 1.98 \times 10^{-6}t - 1.7 \times 10^{-8}t^2,$$

when the surface is that of polished copper. In these equations e is the amount of heat lost in c. g. s. units, that is, the quantity of heat, small calories, radiated per second per square centimeter of surface of the sphere, per degree difference of temperature t, and t is the difference of temperature between the sphere and the enclosure. The medium through which the heat passed was moist air. The following table gives the results.

Difference of temperature t	Value of e. Polished surface.	Value of e. Blackened surface.	Ratio.
5	.000178	.000252	.707
10	.000186	.000266	.699
15	.000193	.000279	.692
20	.000201	.000289	.695
25	.000207	.000298	.694
30	.000212	.000306	.693
35	.000217	.000313	.693
40	.000220	.000319	.693
45	.000223	.000323	.690
50	.000225	.000326	.690
55	.000226	.000328	.690
60	.000226	.000328	.690

TABLE 332.—At Different Pressures

Experiments made by J. P. Nicol in Tait's Laboratory show the effect of pressure of the enclosed air on the rate of loss of heat. In this case the air was dry and the enclosure kept at about 8° C.

Polished surface. t	Polished surface. et	Blackened surface. t	Blackened surface. et
PRESSURE 76 CMS. OF MERCURY.			
63.8	.00987	61.2	.01746
57.1	.00862	50.2	.01360
50.5	.00736	41.6	.01078
44.8	.00628	34.4	.00860
40.5	.00562	27.3	.00640
34.2	.00438	20.5	.00455
29.6	.00378	–	–
23.3	.00278	–	–
18.6	.00210	–	–
PRESSURE 10.2 CMS. OF MERCURY.			
67.8	.00492	62.5	.01298
61.1	.00433	57.5	.01158
55	.00383	53.2	.01048
49.7	.00340	47.5	.00898
44.9	.00302	43.0	.00791
40.8	.00268	28.5	.00490
PRESSURE 1 CM. OF MERCURY.			
65	.00388	62.5	.01182
60	.00355	57.5	.01074
50	.00286	54.2	.01003
40	.00219	41.7	.00726
30	.00157	37.5	.00639
23.5	.00124	34.0	.00569
–	–	27.5	.00446
–	–	24.2	.00391

* "Proc. Roy. Soc." 1872.
† "Proc. Roy. Soc." Edinb. 1869.
See also Compan, Annal. de chi. et phys. 26, p. 526.

COOLING BY RADIATION AND CONVECTION

TABLE 333.—Cooling of Platinum Wire in Copper Envelope

Bottomley gives for the radiation of a bright platinum wire to a copper envelope when the space between is at the highest vacuum attainable the following numbers: —

$t = 408°$ C, $et = 378.8 \times 10^{-4}$, temperature of enclosure 16° C.
$t = 505°$ C, $et = 726.1 \times 10^{-4}$, " " 17° C.

It was found at this degree of exhaustion that considerable relative change of the vacuum produced very small change of the radiating power. The curve of relation between degree of vacuum and radiation becomes asymptotic for high exhaustions. The following table illustrates the variation of radiation with pressure of air in enclosure.

Temp. of enclosure 16° C, $t = 408°$ C.		Temp. of enclosure 17° C, $t = 505°$ C.	
Pressure in mm	*et*	Pressure in mm	*et*
740.	8137.0×10^{-4}	0.094	1688.0×10^{-4}
440.	7971.0 "	.053	1255.0 "
140.	7875.0 "	.034	1126.0 "
42.	7591.0 "	.013	920.4 "
4.	6036.0 "	.0046	831.4 "
0.444	2683.0 "	.00052	767.4 "
.070	1045.0 "	.00019	746.4 "
.034	727.3 "	Lowest reached but not measured	726.1 "
.012	539.2 "		
.0051	436.4 "		
.00007	378.8 "		

TABLE 334.—Effect of Pressure on Loss of Heat at Different Temperatures

The temperature of the enclosure was about 15° C. The numbers give the total radiation in therms per square centimeter per second.

Temp. of wire in C°	Pressure in mm				
	10.0	1.0	0.25	0.025	About 0.1 μ
100°	0.14	0.11	0.05	0.01	0.005
200	.31	.24	.11	.02	.0055
300	.50	.38	.18	.04	.0105
400	.75	.53	.25	.07	.025
500	–	.69	.33	.13	.055
600	–	.85	.45	.23	.13
700	–	–	–	.37	.24
800	–	–	–	.56	.40
900	–	–	–	–	.61

NOTE. — An interesting example (because of its practical importance in electric lighting) of the effect of difference of surface condition on the radiation of heat is given on the authority of Mr. Evans and himself in Bottomley's paper. The energy required to keep up a certain degree of incandescence in a lamp when the filament is dull black and when it is "flashed" with coating of hard bright carbon, was found to be as follows: —

Dull black filament, 57.9 watts.
Bright " " 39.8 watts.

TABLE 335.—Conduction of Heat across Air Spaces (Ordinary Temperatures)

Loss of heat by air from surfaces takes place by radiation (dependent upon radiating power of surface; for small temperature differences proportional to temperature difference; follows Stefan-Boltzmann formula, see p. 313), conduction, and convection. The two latter are generally inextricably mixed. For horizontal air spaces, upper surface warm, the loss is all radiation and conduction; with warm lower surface the loss is greater than for similar vertical space.

Vertical spaces: The following table shows that for spaces of less than 1 cm width the loss is nearly proportional to the space width, when the radiation is allowed for; for greater widths the increase is less rapid, then reaches a maximum, and for yet greater widths is slightly less. The following table is from Dickinson and van Dusen, A. S. Refrigerating Engineers J. 3, 1916.

HEAT CONDUCTION AND THERMAL RESISTANCES, RADIATION ELIMINATED, AIR SPACE 20 CM HIGH

Air space, cm.	Heat conduction. Cal./hour/cm²/° C.				Thermal resistance. Same units.			
	Temperature difference.				Temperature difference.			
	10°	15°	20°	25°	10°	15°	20°	25°
0.5	0.46	0.46	0.46	0.46	2.17	2.17	2.17	2.17
1.0	0.24	0.24	0.24	0.24	4.25	4.20	4.15	4.10
1.5	0.160	0.172	0.182	0.192	6.25	5.80	5.50	5.20
2.0	0.161	0.178	0.200	0.217	6.20	5.60	5.00	4.60
3.0	0.172	0.196	0.208	0.217	5.80	5.10	4.80	4.60

Variation with height of air space: Max. thermal resistance = 4.0 at 1.4 cm air space, 10 cm high; 6.0 at 1.6 cm, 20 cm high; 8.9 at 2.5 cm, 60 cm high.

TABLE 336.—Convection of Heat in Air at Ordinary Temperatures

In very narrow layers of air between vertical surfaces at different temperatures the convection currents, in the main, flow up one side and down the other, with eddyless (stream-line) motion. It follows that these currents transport heat to or from the surfaces only when they turn and flow horizontally, from which fact it follows, in turn, that the convective heat transfer is independent of the height of the surface. It is, according to the laws of eddyless flow, proportional to the square of the temperature difference, and to the cube of the distance between the surfaces. As the flow becomes more rapid (e.g., for a 20° difference and a distance of 1.2 cm) turbulence enters, and the above relations begin to change. For the dimensions tested, convection in horizontal layers was a little over twice that in vertical.

Taken from White, Physical Review, 10. 743, 1917.

Heat Transfer, in the Usual C.G.S. Unit, i.e., Calories per Second per Degree of Thermal Head per Square Cm of Flat Surface, at 22.8° Mean Temperature.

Where two values are given, they show the range among determinations with different methods of getting the temperature of the outer plate. It will be seen that the value of the convection is practically unaffected by this difference of method.

Thermal head.	8 mm gap.		12 mm gap.		24 mm gap.	
	Total.	Convection.	Total.	Convection	Total.	Convection.
0.99°	—	—	.000 083 9 .000 084 8	—	.000 065	—
1.98°	.000 109 110	—	.000 084 0 .000 085 2	.000 000 1 000 4	—	—
4.95°	.000 111	.000 001	000 086 6 88 1	.000 002 8 003 7	.000 090	over .000 025
9.89°	.000 112 113	000 003 003	000 093 7 95 2	.000 010 .000 011	.000 106	over .000 040
19.76°	.000 116	.000 007	000 107 7 100 4	.000 024 026	.000 120	over .000 060

Table 337

CONVECTION AND CONDUCTION OF HEAT BY GASES AT HIGH TEMPERATURES *

The loss of heat from wires at high temperatures occurs as if by conduction across a thin film of stationary gas adhering to the wire (vertical and horizontal losses very similar). Thickness of film is apparently independent of temperature of wire, but probably increases with the temperature of the gas and varies with the diameter of the wire according to the formula $b \cdot \log b/a = 2B$, where B = constant for any gas, b = diameter of film, a, of wire. The rate of convection (conduction) of heat is the product of two factors, one the shape factor, s, involving only a and B, the other a function ϕ of the heat conductivity of the gas. If W = the energy loss in watts/cm, then $W = s(\phi_2 - \phi_1)$. s may be found from the relation

$$\frac{s}{\pi} e^{-\frac{2\pi}{s}} = \frac{a}{B}; \quad \phi = 4.19 \int_0^T k dt,$$

where k is the heat conductivity of the gas at temperature T in calories/cm °C. ϕ_2 is taken at the temperature T_2 of the wire, ϕ_1 at that of the atmosphere. The following may be taken as the conductivities of the corresponding gases at high temperatures:

For hydrogen............ $k = 28 \times 10^{-6}\sqrt{T}\{(1 + .0002T)/(1 + 77T^{-1})\}$
air.................. $k = 4.6 \times 10^{-6}\sqrt{T}\{(1 + .0002T)/(1 + 124T^{-1})\}$
mercury vapor........ $k = 2.4 \times 10^{-6}\sqrt{T}\{1/(1 + 960T^{-1})\}$.

To obtain the heat loss: B may be assumed proportional to the viscosity of the gas and inversely proportional to the density. For air (see Table 338(*b*)) B may be taken as 0.43 cm; for H_2, 3.05 cm; for Hg vapor as 0.078. Obtain s from section (*a*) below from a/B; then from section (*b*) obtain ϕ_2 and ϕ_1 for the proper temperatures; the loss will be $s(\phi_2 - \phi_1)$ in watts/cm.

(*a*) s as Function of a/B

s	a/B	s	a/B	s	a/B	s	a/B
0.0	0.0	5.0	0.453	10	1.696	30	7.738
0.5	0.735×10^{-6}	5.5	0.558	12	2.263	32	8.370
1.0	0.594×10^{-3}	6.0	0.671	14	2.844	34	8.995
1.5	0.725×10^{-2}	6.5	0.788	16	3.438	36	9.622
2.0	2.75×10^{-2}	7.0	0.908	18	4.040	38	10.25
2.5	0.0644	7.5	1.032	20	4.645	40	10.87
3.0	0.1176	8.0	1.160	22	5.263	42	11.50
3.5	0.185	8.5	1.291	24	5.877	44	12.14
4.0	0.265	9.0	1.424	26	6.505	46	12.77
4.5	0.354	9.5	1.561	28	7.122	48	13.14
5.0	0.453	10.0	1.696	30	7.738	50	14.03

(*b*) Table of ϕ in Watts per Cm as Function of Absolute Temp. (°K.)

T° K.	H_2	Air	Hg	T° K.	H_2	Air	Hg
0°	0.0000	0.0000	—	1500°	4.787	0.744	0.1783
100	0.0329	0.0041	—	1700	5.945	0.931	0.228
200	0.1294	0.0168	—	1900	7.275	1.138	0.284
300	0.278	0.0387	—	2100	8.655	1.363	0.345
400	0.470	0.0669	—	2300	10.18	1.608	0.411
500	0.700	0.1017	0.0165	2500	11.82	1.871	0.481
700	1.261	0.189	0.0356	2700	13.56	—	0.556
900	1.961	0.297	0.0621	2900	15.54	—	0.636
1100	2.787	0.426	0.0941	3100	17.42	—	0.719
1300	3.726	0.576	0.1333	3300	19.50	—	0.807
1500	4.787	0.744	0.1783	3500	21.79	—	0.898

* Langmuir Physical Review, 34, p. 401, 1912.

TABLE 338

HEAT LOSSES FROM INCANDESCENT FILAMENTS

(a) Wires of Platinum Sponge Served as Radiators to Room-temperature Surroundings, Hartman, Physical Review, 7, p. 431, 1916

Diameter wire, cm.	900°	1000°	1100°	1200°	1300°	1400°	1500°	1600°	1700°	1800°	1900°	2000°
	(A) Observed heat losses in watts per cm. Absolute temperatures.											
0.0690	1.70	2.26	3.01	3.88	4.92	6.18	7.70	9.63	12.15	15.33	19.25	23.75
0.0420	1.35	1.75	2.26	2.84	3.53	4.29	5.33	6.60	8.25	10.20	12.45	14.75
0.0275	1.12	1.40	1.76	2.23	2.73	3.23	3.91	4.67	5.72	7.00	8.64	10.45
0.0194	0.92	1.15	1.39	1.74	2.12	2.54	3.04	3.64	4.32	5.10	6.10	7.35
	(B) Heat losses corrected for radiation, watts per cm (A–C).											
0.0690	0.91	1.05	1.23	1.36	1.45	1.51	1.54	1.66	2.00	2.56	3.40	4.30
0.0420	0.87	1.02	1.17	1.31	1.42	1.45	1.57	1.76	2.08	2.43	2.80	3.26
0.0275	0.80	0.92	1.05	1.22	1.35	1.37	1.46	1.50	1.67	1.91	2.32	2.70
0.0194	0.70	0.81	0.89	1.03	1.15	1.23	1.31	1.40	1.47	1.51	1.64	1.88
	(C) Computed radiation, watts per cm, $\sigma = 5.61 \times 10^{-12}$.*											
0.0690	0.79	1.21	1.78	2.52	3.47	4.67	6.16	7.97	10.15	12.77	15.85	19.45
0.0420	0.48	0.73	1.09	1.53	2.11	2.84	3.74	4.84	6.17	7.77	9.65	11.85
0.0275	0.32	0.48	0.71	1.01	1.38	1.86	2.45	3.17	4.05	5.09	6.32	7.75
0.0195	0.22	0.34	0.50	0.71	0.97	1.31	1.73	2.24	2.85	3.59	4.46	5.47
	(D) Conduction loss by silver leads, watts per cm.											
0.0420	0.42	0.46	0.49	0.61	0.75	0.88	1.00	1.07	1.13	1.22	—	—
0.0275	0.18	0.21	0.28	0.35	0.43	0.48	0.55	0.57	0.60	0.67	—	—
0.0195	0.06	0.08	0.08	0.09	0.11	0.12	0.14	0.15	0.22	0.23	—	—
	(E) Convection loss by air, watts per cm.											
0.0420	0.45	0.56	0.63	0.70	0.67	0.57	0.59	0.69	0.95	1.21	—	—
0.0275	0.62	0.71	0.77	0.87	0.92	0.89	0.91	0.93	1.07	1.24	—	—
0.0195	0.64	0.73	0.81	0.94	1.04	1.11	1.17	1.25	1.29	1.30	—	—

* This value is lower than the presently (1919) accepted value of 5.72.

(b) Wires of Bright Platinum 40–50 Cm Long Served as Radiators to Surroundings at 300° K. Langmuir, Physical Review, 34, p. 401, 1912

Diameter wire, cm.	500°	700°	900°	1100°	1300°	1500°	1700°	1900°	
	Observed energy losses in watts per cm. Absolute temperatures.								
0.0510	0.22	0.52	0.90	1.42	2.03	2.89	4.10	5.65	
0.02508	0.17	0.39	0.68	1.02	1.45	2.00	2.68	3.55	
0.01262	0.13	0.31	0.53	0.79	1.11	1.46	1.95	2.71	
0.00691	0.12	0.29	0.48	0.72	0.99	1.33	1.79	2.48	
0.00404	0.11	0.24	0.41	0.61	0.84	1.14	1.54	2.13	
	Energy radiated in watts per cm.*								
0.0510	0.002	0.013	0.049	0.137	0.323	0.67	1.25	2.15	
0.02508	0.001	0.007	0.024	0.067	0.159	0.33	0.62	1.06	
0.01262	0.001	0.003	0.012	0.034	0.080	0.17	0.31	0.53	
0.00691	0.000	0.002	0.007	0.019	0.044	0.09	0.17	0.29	
0.00404	0.000	0.001	0.004	0.011	0.026	0.05	0.10	0.17	
	"Convection" losses in watts per cm.								
0.0510	0.22	0.51	0.85	1.28	1.71	2.22	2.85	3.50	
0.02508	0.17	0.38	0.66	0.95	1.29	1.67	2.06	2.49	
0.01262	0.13	0.31	0.52	0.75	1.03	1.29	1.64	2.18	
0.00691	0.12	0.29	0.47	0.70	0.95	1.24	1.62	2.19	
0.00404	0.11	0.24	0.41	0.60	0.81	1.09	1.44	1.96	
	Thickness of theoretical conducting air film.								Means.
0.0510	0.28	0.30	0.33	0.33	0.36	0.37	0.35	0.36	0.34
0.02508	0.30	0.37	0.37	0.41	0.45	0.45	0.51	0.56	0.43
0.01262	0.42	0.42	0.44	0.49	0.56	0.69	0.69	0.47	0.54
0.00691	0.31	0.32	0.38	0.40	0.43	0.47	0.38	0.26	0.37
0.00404	0.27	0.43	0.43	0.47	0.56	0.47	0.40	0.25	0.41
Means.	0.31	0.37	0.39	0.42	0.49	0.49	0.47	0.38	†0.43

* Computed with $\sigma = 5.32$, black-body efficiency of platinum as follows (Lummer and Kurlbaum): 492° K. 0.039; 654°, 0.060; 795°, 0.075; 1108°, 0.112; 1481°, 0.154; 1761° K., 0.180. † Weighted mean.

THE SENSITIVITY OF THE EYE

Definitions: A meter-candle is the intensity of illumination due to a standard candle at a meter distance. The millilambert (0.001 lambert) measures the brightness of a perfectly diffusing (according to Lambert's cosine law) surface diffusing .001 lumen/cm². A brightness of 10 meter-candles equals 1 millilambert. 0.001 ml corresponds roughly to night exteriors, 0.1, to night interiors, 10 ml to daylight interiors and 1000, to daylight exteriors. A brightness of 100,000 meter-candles is about that of a horizontal plane for summer day with sun in zenith, 500, on a cloudy day, 4, 1st magnitude stars just visible, 0.2, full moon in zenith, .001, by starlight; in winter the intensity at noon may drop about $\frac{1}{3}$.

TABLE 339.—Spectral Variation of Sensitiveness as a Function of Intensity

Radiation is easily visible to most eyes from 0.330 μ (violet) to 0.770 μ (red). At low intensities near threshold values (gray, rod vision) the maximum of spectral sensibility lies near 0.503 μ (green) for 90% of all persons. At higher intensities, after the establishment of cone vision, the max. shifts as far as 0.560 μ. See Table 346 for more accurate values of sensitiveness after this shift has been accomplished. The ratio of optical sensation to the intensity of energy increases with increasing energy more rapidly for the red than for the shorter wave-lengths (Purkinje phenomenon); i.e., a red light of equal intensity to the eye with a green one will appear darker as the intensities are equally lowered. This phenomenon disappears above a certain intensity (above 10 millilamberts). Table due to Nutting, Bulletin Bureau of Standards.

The intensity is given for the spectrum at 0.535μ (green).

Intensity (meter-candles) =	.00024	.00225	.0360	.575	2.30	9.22	36.9	147.6	590.4
Ratio to preceding step =	—	9.38	16	16	4	4	4	4	4
Wave-length, λ.	Sensitiveness.								
0.430 μ	0.081	0.093	0.127	0.128	0.114	0.114	—	—	—
0.450	0.33	0.30	0.29	0.31	0.23	0.175	0.16	—	—
0.470	0.63	0.59	0.54	0.58	0.51	0.29	0.26	0.23	—
0.490	0.96	(0.89)	(0.76)	(0.89)	(0.83)	0.50	0.45	0.38	0.35
0.505	1.00	1.00	1.00	1.00	0.99	(0.76)	0.66	0.61	0.54
0.520	0.88	0.86	0.86	0.94	0.99	(0.85)	0.85	0.85	0.82
0.535	0.61	0.62	0.63	0.72	0.91	(0.98)	0.98	0.99	0.98
0.555	0.26	0.30	0.34	0.41	0.62	0.84	0.93	0.97	0.98
0.575	0.074	0.102	0.122	0.168	(0.39)	(0.63)	(0.76)	(0.82)	(0.84)
0.590	0.025	0.034	0.054	0.091	0.27	0.49	0.61	0.68	0.69
0.605	0.008	0.012	0.024	0.056	0.173	0.35	(0.45)	0.54	0.55
0.625	0.004	0.004	0.011	0.027	0.098	0.20	0.27	0.35	0.35
0.650	0.000	0.000	0.003	0.007	0.025	0.060	0.085	0.122	0.133
0.670	0.000	0.000	0.001	0.002	0.007	0.017	0.025	0.030	0.030
λ, maximum sensitiveness	0.503	0.504	0.504	0.508	0.513	0.530	0.541	0.543	0.544

TABLE 340.—Threshold Sensibility as Related to Field Brightness

The eye perceives with ease and comfort a billion-fold range of intensities. The following data were obtained with the eye fully adapted to the sensitizing field, B, the field flashed off, and immediately the intensity, T, of a test spot (angular size at eye about 5°) adjusted to be just visible. This table gives a measure of the brightness, T, necessary to just pick up objects when the eye is adapted to a brightness, B. Intensities are indicated log intensities in millilamberts. Blanchard, Physical Review, 11, p. 81, 1918.

Log B	−7.0	−6.0	−5.0	−4.0	−3.0	−2.0	−1.0	0.0	+1.0	+2.0	+3.0
Log T, white	—	−5.81	−5.42	−4.87	−4.17	−3.30	−2.59	−2.02	−1.42	−0.75	+0.28
T/B	—	1.5	0.38	.13	.068	.050	.026	.0096	.0038	.0018	.0019
Log T, blue	−6.70	−6.38	−5.82	−5.12	−4.23	−3.46	−2.70	−2.18	−1.62	—	—
Log T, green	−6.42	−6.20	−5.62	−5.00	−4.23	−3.39	−2.60	−2.08	−1.62	−0.90	—
Log T, yellow	—	−5.47	−5.17	−4.61	−4.03	−3.33	−2.57	−1.97	−1.62	—	—
Log T, red	—	—	−4.27	−4.00	−3.47	−2.96	−2.43	−1.92	−1.37	−0.90	—

THE SENSIBILITY OF THE EYE

TABLE 341.—Heterochromatic Threshold Sensibility

The following table shows the decrease in sensitiveness of the eye for comparing intensities of different colors. The numbers in the body of the table correspond to the line marked *T/B* of Table 340. The intensity of the field was probably between 10 and 100 millilamberts (25 photons).

Comparison color.		0.693 μ	0.640 μ	0.575 μ	0.505 μ	0.475 μ	0.430 μ
Standard color: red	0.693 μ	0.044	0.088	0.165	0.180	0.107	0.150
yellow	0.575 μ	0.174	0.160	0.032	0.166	0.174	0.134
green	0.505 μ	0.211	0.180	0.138	0.030	0.116	0.126
blue	0.475 μ	0.168	0.180	0.130	0.130	0.068	0.142

TABLE 342.—Contrast or Photometric Sensibility

For the following table the eye was adapted to a field of 0.1 millilambert and the sensitizing field flashed off. A neutral gray test spot (angular size at eye, 5 × 2.5°) the two halves of which had the contrast indicated (½ transparent, ½ covered with neutral screen of transparency = contrast indicated) was then observed and the brightness of the transparent part measured necessary to just perceive the contrast after the lapse of the various times. One eye only used, natural pupil. Blanchard, Physical Review, 11, p. 88, 1918. Values are log brightness of brighter field in millilamberts.

Time in seconds.	0	1	2	5	10	20	40	60
Contrast: 0.00	−2.80	−3.47	−3.82	−4.30	−4.49	−4.60	−4.89	−5.03
0.39	−2.63	−3.36	−3.58	−3.74	−3.85	−3.07	−4.06	−4.23
0.67	−2.40	−3.00	−3.13	−3.22	−3.21	−3.33	−3.46	−3.48
0.87	−2.10	−2.46	−2.49	−2.48	−2.55	−2.54	−2.67	−2.73
0.97	−1.20	−1.57	−1.67	−1.69	−1.59	−1.63	−1.73	−1.78

TABLE 343.—Glare Sensibility

When an eye is adapted to a certain brightness and is then exposed suddenly to a much greater brightness, the latter may be called glaring if uncomfortable and instinctively avoided. Observers naturally differ widely. The data are the means of three observers, and are log brightnesses in millilamberts. The glare intensity may be taken as roughly 1700 times the cube root of the field intensity in millilamberts. Angle of glare spot, 4°. Blanchard, Physical Review, *loc. cit.*

Log. field	−6.0	−4.0	−2.0	−1.0	0.0	+1.0	2.0	3.0	4.0
Log. glare	1.35	1.90	2.60	2.90	3.28	3.60	3.90	4.18	4.48

TABLE 344.—Rate of Adaptation of Sensibility

This table furnishes a measure of the rate of increase of sensibility after going from light into darkness, and the values were obtained immediately from the instant of turning off the sensitizing field. Both eyes were used, natural pupil, angular size of test spot, 4.9°, viewed at 35 cm. Blanchard, *loc. cit.* Retinal light persists only 10 to 20 m when one has been recently in darkness, then in a dimly lighted room; it persists fully an hour when a subject has been in bright sunlight for some time. A person who has worked much in the dark "gets his eyes" quicker than one who has not, but his final sensitiveness may be no greater.

Sensitizing field.	Logarithmic thresholds in millilamberts after									
	0 sec.	1 sec.	2 sec.	5 sec.	10 sec.	20 sec.	40 sec.	60 sec.	5 min.	30 min.	60 min.
White, 0.1 ml	−2.79	−3.82	−4.13	−4.50	−4.75	−4.96	−5.16	−5.32	−5.68	−5.91	−6.06
1.0 ml	−2.20	−2.99	−3.27	−3.79	−4.15	−4.51	−4.82	−5.06	−5.52	−5.86	−6.04
10.0 ml	−1.60	−2.30	−2.53	−3.08	−3.54	−3.94	−4.31	−4.61	−5.22	−5.83	−6.01
100.0 ml	−0.90	−1.66	−2.00	−2.46	−2.64	−2.88	−3.20	−3.84	−4.76	−5.77	−5.97
Blue 0.1 ml	−2.82	−3.92	−4.36	−4.91	−5.27	−5.53	−5.68	−5.81	−6.23	—	—
Green 0.1 ml	−2.69	−4.08	−4.39	−4.82	−5.11	−5.26	−5.43	−5.56	−5.80	—	—
Yellow 0.1 ml	−2.61	−3.84	−4.17	−4.41	−4.65	−4.78	−5.02	−5.09	−5.39	—	—
Red 0.1 ml	−2.32	−2.69	−2.98	−3.37	−3.57	−3.65	−3.73	−3.80	−4.02	—	—

VARIOUS PROPERTIES OF THE EYE

TABLE 345.—Apparent Diameter of Pupil and Flux Density at Retina

Flashlight measures of the pupil (both eyes open) viewed through the eye lens and adapted to various field intensities. For eye accommodated to 25 cm, ratio apparent to true pupil, 1.02, for the unaccommodated eye, 1.14. The pupil size varies considerably with the individual. It is greater with one eye closed; e.g., it was found to be for 0.01 millilambert, 6.7 and 7.2 mm; for 0.6 ml, 5.3 and 6.5; for 6.3 ml, 4.1 and 5.7; for 12.6 ml, 4.1 and 5.7 mm for both and one eye open respectively for a certain individual. At the extreme intensities the two values approach each other. The ratio of the extreme pupil openings is about 1/16, whereas the light intensities investigated vary over 1,000,000-fold (Blanchard and Reeves, partly unpublished data).

Field millilamberts	Observed	(1.14/1.02) × Obs.	Effective area	Flux at retina, lumens per mm^2
0.00001	8 mm	8.96 mm	64 mm^2	8.4×10^{-12}
0.001	7.6	8.51	57	7.6×10^{-10}
0.1	6.5	7.28	42	5.6×10^{-8}
10	4.0	4.48	16	2.1×10^{-6}
1000	2.07	2.35	4.3	5.8×10^{-5}

TABLE 346.—Relative Visibility of Radiation (International Standard—Geneva, 1924)

(See Gibson, Tyndall, Bur. Standards Sci. Paper 475, 1923; Judd, Journ. Opt. Soc. Amer., 21, 267, 1931.)

This table gives the relation between luminous sensation (light) and radiant energy. Data determined for intensities above Purkinje effect. See Table 339. Ratio of light unit (lumens) to energy unit (watt) at .55μ, 0.00162 (Ives, Coblentz, Kingsbury).

λ μ	V_λ	λ μ	V_λ	λ μ	V_λ	λ μ	V_λ	λ μ	V_λ	λ μ	V_λ
.380	.00004	5	.030	.510	.503	5	.915	.640	.175	.710	.0021
5	.00006	.450	.038	5	.608	.580	.870	5	.138	5	.0015
.390	.00012	5	.048	.520	.710	5	.816	.650	.107	.720	.00105
5	.0002	.460	.060	5	.793	.590	.757	5	.082	5	.00074
.400	.0004	5	.074	.530	.862	5	.695	.660	.061	.730	.00052
5	.0006	.470	.091	5	.915	.600	.631	5	.045	5	.00036
.410	.0012	5	.113	.540	.954	5	.567	.670	.032	.740	.00025
5	.0022	.480	.139	5	.980	.610	.503	5	.023	5	.00017
.420	.0040	5	.169	.550	.995	5	.441	.680	.017	.750	.00012
5	.0073	.490	.208	4	1.000	.620	.381	5	.012	5	.00008
.430	.0116	5	.259	.560	.995	5	.321	.690	.0082	.760	.00006
5	.0168	.500	.323	5	.979	.630	.265	5	.0057	5	.00004
.440	.023	5	.407	.570	.952	5	.217	.700	.0041	.770	.00003
								5	.0029		

TABLE 347.—Miscellaneous Eye Data

Light passing to the retina traverses in succession (*a*) front surface of the cornea (curvature, 7.9 mm); (*b*) cornea (equivalent water path for energy absorption, .06 cm); (c.) back surface cornea (curv., 7.9 mm); (*d*) aqueous humour (equiv. H_2O, .34 cm, $n = 1.337$); (*e*) front surface lens (c, 10 mm); (*f*) lens (equiv. H_2O, .42 cm, $n = 1.445$); (*g*) back surface lens (c., 6 mm); (*h*) vitreous humour (equiv. H_2O, 1.46 cm, $n = 1.337$). An equivalent simple lens has its principal point 2.34 mm behind (*a*), nodal point 0.48 mm in front of (*g*), posterior principal focus 22.73 mm behind (*a*), anterior principal focus 12.83 mm. in front of (*a*), curvature, 5.125 mm. At the rear surface of the retina (.15 mm thick) are the rods (30 × 2μ) and cones (10 (6 outside fovea) μ long). Rods are more numerous, 2 to 3 between 2 cones, over 3,000,000 cones in eye. Macula lutea, yellow spot, on temporal side, 4 mm from center of retina, long axis 2 mm. Central depression, fovea centralis, .3 mm diameter, 7000 cones alone present, 6 × 2 or 3μ. In region of distinct vision (fovea centralis) smallest angle at which two objects are seen separate is 50″ to 70″ = 3.65 to 5.14μ at retina; 50 cones in 100μ here; 4μ between centers, 3μ to cone, 1μ to interval. Distance apart for separation greater as depart from fovea. No vision in blind spot, nasal side, 2.5 mm from center of eye, 15 mm in diam.

Persistence of vision as related to color (Allen, Phys. Rev. 11, 257, 1900) and intensity (Porter, Pr. Roy. Soc. 70, 313, 1912) is measured by increasing speed of rotating sector until flicker disappears: for color, .4μ, .031 sec.; .45μ, .020 sec.; .5μ, .015 sec.; .57μ, .012 sec.; .68μ, .014 sec.; .76μ, .018 sec.; for intensity, .06 meter-candle, .028 sec.; 1 mc, .020 sec.; 6 mc, .014 sec.; 100 mc, .010 sec; 142 mc., .007 sec.

Sensibility to small differences in color has two pronounced maxima (in yellow and green) and two slight ones (extreme blue, extreme red). The sensibility to small differences in intensity is nearly independent of the intensity (Fechner's law) as indicated by the following data due to König:

I/I_0	1,000,000	100,000	10,000	1000	100	50	10	5	1	0.1	I_0 in mc
dI/I, white.......	.036	.019	.018	.018	.030	.032	.048	.059	.123	.377	.00072
.60 μ.......	—	.024	.016	.020	.028	.038	.061	.103	.212	—	.0056
.50 μ.......	—	—	.018	.018	.024	.025	.036	.049	.080	.133	.00017
.43 μ.......	—	—	—	.018	.025	.027	.040	.049	.074	.137	.00012

PHOTOMETRIC DEFINITIONS AND UNITS

Radiant flux = Φ = rate of flow of radiation as energy, measured as ergs per second or watts.

Luminous flux = F or Ψ = rate of flow of radiation measured according to power to produce visual sensation. Although strictly thus defined, for photometric purposes it may be regarded as an entity, since the rate of flow for such purposes is invariable. Unit is the *lumen*, the flux emitted in a unit solid angle (steradian) by a point source of unit candle power.

Visibility of radiation of wave-length λ = K_λ = ratio of luminous to radiant flux for that λ, = F_λ / Φ_λ.

Mechanical equivalent of light = ratio of Φ / F for the λ of max. visibility expressed in ergs/sec/lumen or watts/lumen; it is the reciprocal of max. visibility. See p. 335.

Luminosity at wave-length λ = $(K_\lambda)(\Phi_\lambda)$. Spectral luminosity curve expresses this as a function of λ and is different for various sources.

Luminous efficiency = F/Φ expressed in lumens/watt.

Luminous intensity of (approximate) point source = I = solid-angle (ω) density of luminous flux in direction considered = $dF/d\omega$, or F/ω when the intensity is uniform. Unit, the *candle*.

Illumination on surface = E = flux density on surface = dF/dS (S is surface area) = F/S when uniform. Units, meter-candle, foot-candle, phot, lux.

Lux = one lumen per m^2; phot one lumen per cm^2.

Brightness of a luminous surface may be expressed in two ways:

(1) $b_I = dI/dS. \cos\theta$ where θ is the angle between normal to surface and the line of sight; normal brightness when θ is zero.

(2) $b_F = dF/dS'$ assuming that the surface is a perfect diffuser, obeying cos. law of emission or reflection. Unit, the lambert.

Specific luminous radiation, E' = luminous flux density emitted by a surface, or the flux emitted per unit of emissive area, expressed in lumens per cm^2. For surfaces obeying Lambert's cosine law, $E' = \pi b_0$.

The lambert, the cgs unit of brightness, is the brightness of a perfectly diffusing surface radiating or reflecting one lumen per cm^2. Equivalent to a perfectly diffusing surface with illumination of one phot. A perfectly diffusing surface emitting one lumen per ft^2 has a brightness of 1.076 millilamberts. Brightness in candles per cm^2 is reduced to lamberts by multiplying by π.

A uniform point source of one candle emits 4π lumens.
One lumen is emitted by .07958 spherical candle power.
One lumen emitted per ft^2 = 1.076 millilamberts (perfect diffusion).
One spherical candle power emits 12.57 lumens.
One lux = 1 lumen incident per m^2 = .0001 phot = .1 milliphot.
One phot = 1 lumen incident per cm^2 = 10,000 lux = 1000 milliphots.
One milliphot = .001 phot = .929 foot-candle.
One foot-candle = 1 lumen incident per ft^2 = 1.076 milliphots = 10.76 lux.
One lambert = 1 lumen emitted per cm^2 of a perfectly diffusing surface.
One millilambert = .929 lumen emitted per ft^2 (perfect diffusion).
One lambert = .3183 candle per cm^2 = 2.054 candles per in^2.
One candle per cm^2 = 3.1416 lamberts.
One candle per in^2 = .4868 lambert = 486.8 millilamberts.

Adapted from Reports of Committee on Nomenclature and Standards of Illuminating Engineering Society. 1916 to 1918.

TABLE 349.—Photometric Standards

In Germany the Hefner lamp is most used; in England the Pentane lamp and sperm candles; in France the Carcel lamp is preferred; in America the Pentane and Hefner lamps are used to some extent, but candles are largely employed in gas photometry. For the photometry of electric lamps, and in accurate photometric work, electric lamps, standardized at a national standardizing institution, are employed.

The "International candle" designates the value of the candle as maintained by co-operative effort between the national laboratories of England, France, and America; and the value of various photometric units in terms of this is given in the following table (Circular No. 15 of the Bureau of Standards).

1 International Candle = 1 Pentane Candle.
1 International Candle = 1 Bougie Decimale.
1 International Candle = 1 American Candle.
1 International Candle = 1.11 Hefner Unit.
1 International Candle = 0.104 Carcel Unit.

1. Standard Pentane Lamp, burning pentane............ 10.0 candles.
2. Standard Hefner Lamp, burning amyl acetate......... 0.9 candles.
3. Standard Carcel Lamp, burning colza oil............ 9.6 candles.
4. Standard English Sperm Candle, approximately........ 1.0 candles.

TABLE 350.—The Waidner-Burgess Standard of Light

The Waidner-Burgess standard light consists in immersing a hollow inclosure in a bath of molten platinum and observing the light from the inclosure during the period of freezing. The exceptionally pure Pt was in a thorium oxide crucible heated by an induction furnace. At all times before and after test the Pt was 99.997% pure. Reproducible to 0.1% the brightness is

58.84 International Candles per cm^2

(Wensel, Roeser, Barbrow, Caldwell, Bur. Standards Journ. Res., 6, 1103, 1931.)

TABLE 351.—Intrinsic Brightness of Various Light Sources

	Barrows.	Ives & Luckiesh.		National Electric Lamp Association.
	C. P. per Sq. In. of surface of light.	C. P. per Sq. In. of surface of light.	C. P. per Sq. Mm. of surface of light.	C. P. per Sq. In. of surface of light.
Sun at Zenith	600,000	–	–	600,000
Crater, carbon arc	200,000	84,000	130.	200,000
Open carbon arc	10,000–50,000	–	–	10,000–50,000
Flaming arc	5,000	–	–	5,000
Magnetite arc	–	4,000	6.2	–
Nernst Glower	800–1,000	(115v.6 amp. d.c.) 3,010	4.7	(1.5 w.p.c.) 2,200
Tungsten incandescent, 1.15 w. p. c.	–	–	–	1,000
Tungsten incandescent, 1.25 w. p. c.	1,000	1,000	1.64	875
Tantalum incandescent, 2.0 w. p. c.	750	580	0.9	750
Graphitized carbon filament, 2.5 w. p. c.	625	750	1.2	625
Carbon incandescent, 3.1 w. p. c.	480	485	0.75	480
Carbon incandescent, 3.5 w. p. c.	375	400	0.63	375
Carbon incandescent, 4.0 w. p. c.	300	325	0.50	–
Inclosed carbon arc (d. c.)	100–500	–	–	100–500
Inclosed carbon arc (a. c.)	–	–	–	75–200
Acetylene flame (1 ft. burner)	75–100	53.0	0.082	75–100
Acetylene flame (¼ ft. burner)	–	33.0	0.057	–
Welsbach mantle	20–25	31.9	0.048	20–50
Welsbach (mesh)	–	56.0	0.067	–
Cooper Hewitt mercury vapor lamp	16.7	14.9	0.023	17
Kerosene flame	4–8	9.0	0.014	3–8
Candle flame	3–4	–	–	3–4
Gas flame (fish tail)	3–8	2.7	0.004	3–8
Frosted incandescent lamp	4–8	–	–	2–5
Moore carbon-dioxide tube lamp	0.6	–	–	0.3–1.75

Taken from *Data*, 1911.

BRIGHTNESS OF BLACK BODY. CROVA WAVE-LENGTH. MECHANICAL EQUIVALENT OF LIGHT. LUMINOUS INTENSITY AND EFFICIENCY OF BLACK BODY

The values of L, the luminous intensity, are given in light watts/steroradian/cm² of radiating surface $= (1/\pi) \int_0^\infty V_\lambda E_\lambda d\lambda$, where V_λ is the visibility of radiation function.

Mechanical equivalent. The unit of power is the watt; of lumininous flux, the lumen. The ratio of these two quantities for light of maximum visibility, $\lambda = 0.556\ \mu$, is the stimulus coefficient V_m; its reciprocal is the (least) mechanical equivalent of light, i.e., least since applicable to radiation of maximum visibility. A better term is "luminous equivalent of radiation of maximum visibility." One lumen = 0.001496 watts (Hyde, Forsythe, Cady); or 1 watt of radiation of maximum visibility ($\lambda = 0.556\ \mu$) = 668 lumens.

White light has sometimes been defined as that emitted by a black body at 6000° K.

The Crova wave-length for a black body is that wave-length, λ, at which the luminous intensity varies by the same fractional part that the total luminous intensity varies for the same change in temperature.

TABLE 352.—Brightness, Crova Wave-length of Black Body, Mechanical Equivalent of Light *

Temp. ° K.	Brightness, candles per cm²	Crova wave-length, μ	Mech. equiv. watts per l.
1700°	5.1	0.584	0.001478
1750	7.6	0.583	—
1800	11.3	0.582	0.001491
1850	16.3	0.581	—
1900	23.1	0.580	0.001498
1950	32.2	0.579	—
2000	44.3	0.578	0.001498
2050	60.0	0.577	—
2100	80.1	0.576	0.001497
2150	105.7	0.576	—
2200	137.6	0.575	0.001496
2250	177.	0.574	—
2300	226.	0.574	0.001497
2350	284.	0.573	—
2400	354.	0.572	0.001497
2450	438.	0.572	—
2500	537.	0.571	0.001502
2550	651.	0.570	—
2600	785.	0.570	0.001511
2650	939.	0.569	—
Mean			0.001496

* Hyde, Forsythe, Cady, Phys. Rev. 13, p. 45, 1919.

TABLE 353.—Luminous and Total Intensity and Radiant Luminous Efficiency of Black Body *

T, degrees absolute.	Luminous intensity L watt cm²	Total intensity $\sigma_0 T^4$ watt/cm²	Radiant luminous efficiency.
1,200	2.34×10^{-5}	3.762	.000006
1,600	3.45×10^{-3}	1.189	.000290
1,700	8.46×10^{-3}	1.515×10	.000558
1,800	1.88×10^{-2}	1.905×10	.000987
1,900	3.85×10^{-2}	2.365×10	.00163
2,000	7.34×10^{-2}	2.903×10	.00253
2,100	1.32×10^{-1}	3.529×10	.00374
2,200	2.26×10^{-1}	4.250×10	.00532
2,300	3.69×10^{-1}	5.077×10	.00727
2,400	5.79×10^{-1}	6.020×10	.00962
2,500	8.77×10^{-1}	7.087×10	.0124
2,600	1.29	8.291×10	.0156
3,000	4.66	1.470×10^2	.0317
4,000	3.85×10	4.645×10^2	.0829
5,000	1.36×10^2	1.134×10^3	.1201
6,000	3.26×10^2	2.351×10^3	.1386
7,000	6.03×10^2	4.356×10^3	.1385
8,000	9.59×10^2	7.432×10^3	.1290
10,000	1.84×10^3	1.814×10^4	.1014

* Coblentz, Emerson, Bul. Bureau of Standards, 14, p. 255, 1917.

NOTE. — Minimum energy necessary to produce the sensation of light: Ives, 38×10^{-10}; Russell, 7.7×10^{-10}; Reeves, 19.5×10^{-10}; Buisson, 12.6×10^{-10} erg. sec. (Buisson, J. de Phys. 7, 68, 1917.)

Color temperature (temp. black-body same color) 500 w. gas-filled lamp (22 l/w) 3082°k; 900 w. gas-filled movie lamp, 22.7 l/w, 3086°k, crater 65v. 10 amp. arc, solid carbon, 3780°k cored carbon 3420°k Priest, 1922.

TABLE 354.—Color of Light Emitted by Various Sources *

Source.	Color, per cent white.	Hue.	Source.	Color, per cent white.	Hue.
Sunlight	100	—	N-filled tungsten, 0.50 wpc	45	584
Average clear sky	60	472	N-filled tungsten, 0.35 wpc	53	584
Standard candle	13	593	Mercury vapor arc	70	490
Hefner lamp	14	593	Helium tube	32	598
Pentane lamp	15	592	Neon tube	6	605
Tungsten glow lamp, 1.25 wpc	35	588	Crater of carbon arc, 1.8 amp	59	585
Carbon glow lamp, 3.8 wpc	25	592	Crater of carbon arc, 3.2 amp	62	585
Nernst glower, 1.50 wpc	31	587	Crater of carbon arc, 5.0 amp	67	583
N-filled tungsten, 1.00 wpc	34	586	Acetylene flame (flat)	36	586

* Jones, L. A., Trans. Ill. Eng. Soc., Vol. 9 (1914).

RELATIVE BLUE BRIGHTNESS, B, AND BRIGHTNESS IN CANDLES PER CM.^{2} C, OF SOME INCANDESCENT OXIDES AT VARIOUS RED (0.665μ) BRIGHTNESS TEMPERATURES, S_R

Material	S_R = 1500		1700		1800		1900		2000	
	B	C	B	C	B	C	B	C	B	C
Black body	.026	0.79	0.27	5.0	0.74	11.	1.80	23.	3.9	44.
Tungsten	.038	.84	.41	5.9	1.11	14.	2.7	33.	6.3	74.
Urania, gas air and oxy-gas	.028	1.02	.31	6.6	.84	15.	2.0	35.	4.5	78.
Ceria, pure: Oxy-gas	.035	1.08	.32	6.3	.83	14.	1.9	31.	4.0	62.
" , yellow: "	.032	1.04	.32	7.1	.85	17.	2.0	40.	4.0	88.
" , brown: "	.033	1.15	.30	6.7	.83	15.	1.68	33.	3.5	68.
Oxides of Ce group: Oxy-gas.	.031	.97	.34	6.3	.92	14.	2.3	33.	5.0	71.
Neodymia: Oxy-gas	.032	1.17	.33	6.9	.92	15.	2.3	33.	5.0	64.
Lanthana: "	.033	1.11	.34	6.6	.89	15.	2.1	33.	4.5	64.
Erbia: "	.047	1.71	.45	8.1	1.17	16.	2.7	33.	5.6	63.
Yttria, pure: Oxy-gas	.067	1.18	.61	7.3	1.56	17.	3.6	32.	7.3	63.
" , 95% pure: "	.047	1.20	.46	7.3	1.19	16.	2.8	36.	5.9	75.
Zirconia: Oxy-gas	.058	.73	.55	3.6	1.43	8.	3.3	15.	7.0	30.
Thoria: "	.033	1.44	.56	7.5	1.40	16.	3.1	32.	6.3	63.
Alumina: "	.076	1.45	.87	9.4	2.5	22.	6.1	49.	13.6	103.
Beryllia: "	.086	1.62	.99	9.7	2.8	22.	6.9	49.	15.4	104.
Magnesia: "	.21	2.4	1.31	11.0	2.8	22.	5.6	43.	10.2	79.
Thoria 1% ceria: Oxy-gas	.078	1.45	.70	8.6	1.71	19.	4.1	43.	8.4	90.
" " urania: "	.069	1.33	.67	8.3	1.77	19.	4.1	44.	8.7	93.
" trace urania: "	.059	1.33	.68	8.3	1.93	19.	4.8	44.	10.5	93.
" 1% neodymia: "	.046	1.43	.43	7.1	1.14	15.	2.6	29.	5.5	56.
" " Mn oxide: "	.035	1.13	.37	6.1	1.01	13.	2.4	28.	5.3	56.

NOTE.—1 microcalorie through 1 cm^2 at 1 m = 0.034 sperm calorie = 0.0385 Hefner unit (no diaphragm) = 0.043 Hefner unit (diaphragm 14 × 50 mm). Coblentz, Bull. Bur. of Stds., 11, 87, 1914.

EFFICIENCY OF VARIOUS ELECTRIC LIGHTS

Bryant and Hake, Eng. Exp. Station, Univ. of Ill.	Amperes.	Terminal Watts.	Lumens.	Kw-hours for 100,000 Lumen-hours.	Total cost per 100,000 Lumen-hours at 10 cts. per Kw-hour.
Regenerative d.-c., series arc	5.5	385	11,670	3.3	0.339
Regenerative d.-c., multiple arc	5.5	605	11,670	5.18	0.527
Magnetite d.-c., series arc	6.6	528	7,370	7.16	0.729
Flame arc, d.-c., inclined electrodes	10.0	550	8,640	6.37	0.837
Mercury arc, d.-c., multiple	3.5	385	4,400	15.92	0.89
Flame arc, d.-c., inclined electrodes	8.0	440	6,140	7.16	0.966
Flame arc, d.-c., vertical electrodes	8.0	440	6,140	7.16	0.966
Luminous arc, d.-c., multiple	6.6	726	7,370	9.85	0.988
Open arc, d.-c., series	9.6	480	5,025	9.55	1.079
Magnetite arc, d.-c., series	4.0	320	2,870	11.15	1.13
Flame arc, a.-c., vertical electrodes	10.0	467	5,340	8.75	1.275
Flame arc, a.-c., inclined electrodes	10.0	467	5,340	8.75	1.275
Open arc, d.-c., series	6.6	325	2,920	11.15	1.305
Tungsten series	6.6	75	626	12.0	1.384
Flame arc, a.-c., inclined electrodes	8.0	374	3,910	9.55	1.405
Inclosed arc, d.-c., series	6.6	475	3,315	14.32	1.459
Luminous arc, d.-c., multiple	4.0	440	2,870	15.32	1.547
Tungsten, multiple	0.545	60	475	12.6	1.55
Nernst, a.-c., 3-glower	1.87	414	2,160	19.2	1.88
Nernst, d.-c., 3-glower	1.87	414	2,160	19.2	1.90
Inclosed arc, a.-c., series	7.5	480	2,410	19.9	2.05
Inclosed arc, a.-c., series	6.6	425	2,020	21.3	2.193
Tantalum, d.-c., multiple	—	40	199	21.1	2.31
Tantalum, a.-c., multiple	—	40	199	21.1	2.504
Carbon, 3.1 w. p. c., multiple	—	49.6	166	29.9	3.24
Carbon, 3.5 w. p. c., series	6.6	210	626	33.6	3.47
Carbon, 3.5 w. p. c., multiple	—	56	166	33.7	3.50
Inclosed arc, d.-c., multiple	5.0	550	1,535	35.8	3.66
Inclosed arc, d.-c., multiple	3.5	385	1,030	37.4	3.84
Inclosed arc, a.-c., multiple	6.0	430	1,124	38.3	3.94
Inclosed arc, a.-c., multiple	4.0	285	688	41.4	4.265

Ives, Phys. Rev., V, p. 390, 1915 (see also VI, p. 332, 1915); computed **assuming 1 lumen = 0.00159 watt.**	Commercial Rating	Lumens per Watt.	Luminous Watts Flux ÷ Watts Input or True Efficiency.
Open flame gas burner	Bray 6′ high pressure	0.22	0.00035
Petroleum lamp		.26	.0004
Acetylene	1.0 liters per hour	67	.0011
Incandescent gas (low pressure)	.350 lumens per B. t. u. per hr.	1.2	.0019
Incandescent gas (high pressure)	.578 lumens per B. t. u. per hr.	2.0	.0031
Nernst lamp		4.8	.0076
Moore nitrogen vacuum tube	220-v. 60-cycle, 113 ft.	5.21	.0083
Carbon incandescent (treated filament)	4-watts per mean hor. C. P.	2.6	.0041
Tungsten incandescent (vacuum)	1.25 watts per hor. C. P.	8.	.013
Carbon arc, open arc	9.6 amp. clear globe	11.8	.019
Mazda, type C	500-watt multiple .7 w. p. c.	15.	.024
Mazda, type C	600 C. P. -20 amp. .5 w. p. c.	19.6	.031
Magnetite arc, series	6.6 amp. direct current	21.6	.034
Glass mercury arc	40-70 volt; 3.5 amperes	23.	.036
Quartz mercury arc	174-197 volt; 4.2 amperes	42.	.067
Enclosed white flame carbon arc	10 ampere, A. C.	26.7	.042
" " " " "	6.5 ampere, D. C.	35.5	.057
Open arc " " inclined	10 ampere, A. C.	29.	.046
" " " " "	10 ampere, D. C.	27.7	.044
Enclosed yellow flame carbon arc	10 ampere, A. C.	31.4	.050
" " " " "	6.5 ampere, D. C.	34.2	.054
Open arc, " " , inclined	10 ampere, A. C.	41.5	.066
" " " " "	10 ampere, D. C.	44.7	.071

TABLE 357.—Color Temperature, Brightness Temperature, and Brightness of Various Illuminants

Source	T_c	S (λ = .665)	Brightness c/cm²
Gas flame			
Batswing	2160		
Candle shape about 10 cm high	1875		
Hefner as a whole	1880		
Candle			
Sperm	1930		
Paraffin	1925		
Pentane			
10-cp. std.	1920		
Kerosene			
Flat wick	2055	1500	1.27
Round wick	1920	1530	1.51
4 w p. c. carbon	2080	2030	54.9
3.1 w p. c. treated carbon	2165	2065	70.6
2.5 w p. c. gem	2195	2130	78.1
2 w p. c. osmium	2185	2035	60.8
2 w p. c. tantalum	2260	2000	53.1
Acetylene as a whole	2380		
One spot	2465	1660	6.69
Mees burner	2360	1730	10.8
1.25 w p. c. tungsten	2400	2150	125
2.3 w p. c. Nernst	2400	2320	258
Sun			
Outside atmosphere	6500		224000
At earth's surface	5600		165000

TABLE 358.—Temperature, Efficiency, and Brightness of Vacuum Lamps

Lamp	Lumens per watt	Maximum temperature, K.	Maximum brightness candles/cm²
50-watt carbon	3.3	2115°	55
50-watt gem	4.0	2180	78
50-watt tantalum	4.9	2160	53
10-watt tungsten	7.7	2355	128
25-watt tungsten	9.8	2450	193
40-watt tungsten	10	2460	206
60-watt tungsten	10.1	2465	211

TABLE 359.—Temperature, Efficiency, and Brightness of Gas-Filled Tungsten Lamps

Lamp	Lumens per watt	Maximum temperature, K.	Average color temperature, K.	Maximum brightness of filament candles/cm²
Regular gas-filled lamps:				
50-watt	10.0	2685°	2670°	469
75-watt	11.8	2735	2705	563
100-watt	12.9	2760	2740	605
200-watt	15.2	2840	2810	781
300-watt	16.3	2870	2840	862
500-watt	18.1	2930	2920	1015
1000-watt	20.0	2990	2980	1225
2000-watt	21.2	3020	3000	1350
Special lamps:				
1000-watt stereopticon	24.2	3185	3175	2065
900-watt movie	27.3	3290	3220	2660
10-kw	31.0	3350	3300	3050
30-kw	31.0	3350	3300	3050
Daylight lamps:				
200-watt	10.0	2860	....	....
500-watt	11.2	2960	....	....
Photographic:				
750-watt	....	3065	....	....
1500-watt	....	3105	....	....

TABLE 360.—Energy Distribution for Some Tungsten Lamps

(Taken from Forsythe, Christison, Gen. Electr. Rev., p. 662, 1929.)

	500 w, 1000 hr.		500 w, 100 hr.		900 w movie		tungsten arc*	
	%	milli-watts	%	milli-watts	%	milli-watts	%	milli-watts
0.31–0.29μ	0.011	0.00044	0.015	0.006	0.030	0.0028	0.095	0.0108
below 0.325μ	.032	.0013	.042	.0017	.083	.0076	.26	.030
" 0.35	.08	.003	.10	.004	.18	.017	.52	.059
" 0.40	.31	.012	.38	.015	.63	.058	1.53	.17
0.40–0.76	15.7	.63	16.7	.67	19.4	1.8	27.0	3.1
Total		4.0		4.0		9.2		11.4

* Calculated for cm² of molten tungsten.

TABLE 361.—Brightness of Filaments and Bulbs of Some Tungsten Lamps and of Some Other Sources for Comparison

Lamp	Brightness measured at—	Brightness candles/cm²
Kerosene flame	Flat wick	1.2
4-watt per candle carbon lamp	Filament	55.0
40-watt vacuum tungsten lamp	Filament	206
40-watt vacuum tungsten lamp	Bulb-frosted	2.5
40-watt golden Mazda	Bulb	2.0
50-watt white Mazda	Filament	408
50-watt white Mazda	Bulb	1.3
75-watt white Mazda sprayed	Filament	563
75-watt white Mazda sprayed	Bulb	2.1
2000-watt gas-filled Mazda	Filament	1,350
2000-watt gas-filled Mazda	Between coil	3,000
2000-watt gas-filled Mazda	Bulb-frosted	130
Sun as observed at earth's surface	....	165,000
Clear sky, average	....	.4

TABLE 362.—Characteristics of Some Miniature Lamps

(Forsythe, Watson, Gen. Electr. Rev., 34, 734, 1931.)

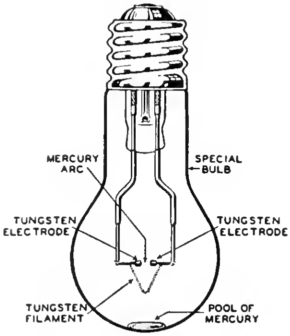
Automobile Mazda lamps						Flash-light lamps				
No.	Service	Volts	Candle power	Watts per sph. candle	Max. T °K.	No.	Volts	Candle power	Watts per sph. candle	Max. T °K.
63	Rear, instrument bd.	6.85	2.9	1.32	2820	19	1.25	0.19	4.10	2570
67	Step, aux. headlight	13.5	2.9	1.27	2810	1	2.25	.40	1.39	2665
81	Dome, panel	6.9	6.3	1.01	2915	11	2.33	.46	1.36	2665
87	Signal	6.75	14.4	.80	2980	35	2.40	1.45	1.35	2635
89	Dome, panel	13.5	6.3	.99	2870	14	2.47	.54	1.41	2700
1110	Headlight, depres. beam	6.5	21.5	.76	2975	16	2.47	.52	1.39	2565
1129	Head and spotlight	6.5	20.5	.76	2930	13	3.70	.98	1.11	2670
1133	" " "	6	31.9	.70	3045	17	3.70	1.02	1.06	2595
1141	Headlight	13	21.9	.70	2960	31	6.15	2.14	.87	2770
1142	Motor coach	12.5	20.6	.80	2885					
1150	Side and headlight	44	21.7	.99	2815	*	1.5	.028	6.0	2115
1158	Ford 2 fil. headlight	6.5	20.9	.81	2925	†	10	80	.62	3160
		....	1.9	2.2	2500	‖	5	48	.63	3200
1183	Spotlight	5.5	49.1	.72	3055	§	8.5	55	.62	3120
1000	Headlight, depres. beam	6	31	.73	2965	**	6	.60	1.52	2485

* Surgical (grain-o'-wheat) 2 mm diam., 8.7 mm long, 0.06 g. † RCA photophone photo-tube exciter. ‖ R C A recorder. § Western Electric sound-picture photo-tube exciter. ** Radio 40.

Feb., 1932. Gen. Electr. Rev., 50 K watt; 120 v; 3300°K.; 1,400,000 lumens; max. candle power 166,000 24 lumens/watt. 10 K watt; 120 v; 3300°K.; 280,000 lumens; max. candle power 33,000; 24 lumens/watt.

TABLE 363.—Characteristics of Sunlight Mazda Lamp (S1) 300 Watts a.c. Combined Incandescent Tungsten, Mercury Arc, Special High Transmission Bulb

For more detailed data see Taylor, Journ. Opt. Soc. Amer., 21, 20, 1931; Forsythe, Barnes, Easley, loc.cit. p. 30, Gen. Electr. Rev., 33, 358, 1930.



Characteristics of S1 lamp: distance between electrodes 5.4 mm. Current 31 + amp., voltage 11 volts; light output 5670 lumens. Efficiency, 17.6 lumens/watt; % light from mercury arc, 20; light from filament 100 lumens; max. temp. electrodes 3200° K, of filament 2330° K. Temp. of Hg 285° C, pressure of Hg vapor, 177 mm Hg.

Transmission of 1 mm of glass used:

λ in Angstroms.........	2500	2600	2700	2800	2900	3100	3300	3500	4000	5000
% transmissible	10	20	33	52	67.5	88	89	90	92	92

Energy Flux in Microvolts/cm²

	S1 Lamp *	Sunlamp Unit * †	Quartz Hg Arc * §	Sun ‡
Below 2000 A	0.6	2.6	37	0.0
2900-3000	2.4	12.	12	0.64
2800-3100	7.7	41.	39	24.
2900-3200	19.3	103.	70	140.

* 1m from center of arc.
† 3.75 amp. 72 v in lamp, no reflector.
§ In center of beam.
‡ Directly overhead.

Per cent Total Energy Flux in various Spectrum Regions

	<3200A	3200–4000A	4000–7600A	7600–17000A	>17000A
Continuous spectrum....	.03	.22	8.8	....	....
Line spectrum..........	.95	.79	(1.37)*	....	....
Both....................	.98	1.01	10.2	45.8	42.0

* Includes Hg red lines.

TABLE 364.—Characteristics of Photoflash Lamp

(Forsythe, Earley, Journ. Opt. Soc. Amer., 21, 685, 1931.)

G. E. Photoflash lamp burns electrically ignited 65 mg A1 foil, .00004 cm thick in closed glass bulb with excess of O_2.
Light output, 47,000 lumens, sec.
Light equals that of 100-watt Mazda for 37 sec. $\left\{\begin{array}{l}\text{Max. intensity 4,500,000 lumens}\\ \text{Over 3,000,000 for 0.005 sec.}\end{array}\right.$
Flashes start in 0.01 sec. with 110 v. Flash lasts 0.066 sec. Time to max. 0.014 sec.

TABLE 365.—Visibility of White Lights

Range	Candle Power 1	Candle Power 2
1 sea-mile = 1855 meters........................	.47	.41
2 " "	1.9	1.6
5 " "	11.8	10

1 Paterson, Dudding. 2. Deutsche Seewarte.

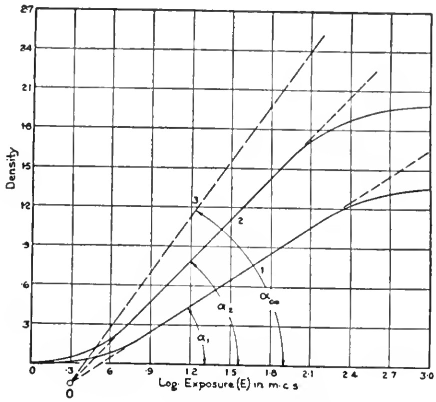
TABLE 366.—Sensitometric Constants of Type Plates and Films, Definitions

Ordinates are density (D); abscissae, logs of exposure ($\log E$).

Density (D) is the absorbing power of the silver deposit.

If F_0 is the luminous flux incident upon the deposit,

F_1 the luminous flux transmitted,
T, the transmission, O, the opacity,
D, the density, then
$T = F_1/F_0$; $O = 1/T = F_0/F_1$
$D = \log_{10} O = \log_{10} 1/T = \log_{10} F_0/F_1$



Typical Characteristic Curves

Exposure (E): $E = It$ (expressed in meter-candle seconds, mcs), I = illumination (meter-candles, mc) incident on the photographic material during exposure, t = exposure time in seconds.

Speeds given in the following table were obtained with a light approximately equivalent to mean noon sunlight in spectral composition.

Gamma (γ): Gamma is defined as the tangent of angle alpha (α).

Gamma infinity (γ_∞): γ_∞ is defined as a theoretical limiting value to which gamma approaches as the development time is increased.[1]

$$\gamma_\infty = \frac{\gamma_1}{1 - e^{-Kt_1}}$$

Velocity Constant of Development (K): $K = \frac{1}{t} \log_e \frac{\gamma_1}{\gamma_2 - \gamma_1}$.

Time of Development for Gamma of Unity ($t_\gamma = 1.0$): A convenient practical specification of development rate.

Fog (F): Fog is the density produced when material is developed without exposure. Values in the table are when development is carried to a gamma of unity.

Latitude (L): L = length of the projection (expressed in exposure units) of the straight line portion on the $\log_{10} E$ axis, assuming development to a gamma of unity.

Inertia (i): i = the value of exposure where the straight line portion of the characteristic curve extended cuts the $\log_{10} E$ axis. The inertia is in general a function of the extent to which development is carried. Values of i given in the table were determined for a gamma of unity.

Speed (S): $S = \frac{1}{i} \times 10$.

In the determination of the values given in Table 368 a developing solution made up according to the following formula was used:

TABLE 367.—Formula for Laboratory Pyrogallol Developer

Solution A		Solution B	
Na_2SO_3	70 g	$NaCO_3$, anhyd.	75 g
$NaHSO_3$	17	KBr	1
Pyrogallol	20	Water to 1 liter	
Water to 1 liter			

Temperature 20° C. For use, mix equal volumes of A and B.

[1] Sheppard and Mees, Investigations on the theory of the photographic process. London, Longmans, 1907.

TABLE 368.—Sensitometric Constants of Type Plates and Films

Material	Fog	K	γ_∞	$T\gamma = 1.0$	Lat.	i	Speed
Motion picture film:							
Extra fast	0.15	0.15	1.4	8.5	200	0.011	900
Normal	.10	.16	1.6	6.0	200	.020	500
Panchromatic	.12	.16	1.6	6.0	300	.017	600
Positive	.03	.30	2.7	1.5	50	.33	30
Portrait extra fast	.15	.14	1.4	8.5	200	.011	900
Portrait normal	.10	.15	1.8	6.0	200	.020	500
Amateur film	.10	.15	1.8	5.5	100	.025	400
"Focal plane" plate	.15	.15	1.8	5.5	100	.012	800
Commercial ordinary	.05	.17	2.2	3.5	75	.040	250
Commercial orthochromatic	.10	.17	2.2	3.5	75	.033	300
Commercial panchromatic	.12	.17	2.2	3.5	75	.025	400
Process ordinary	.03	.30	3.0	1.5	25	.33	30
Process panchromatic	.10	.30	3.0	1.5	25	.10	100
Lantern slide plate	.03	.34	3.2	1.0	25	.65	15

TABLE 369.—Resolving Power, Sharpness, and Astro Gamma, Definitions

Resolving Power. (R). The capacity of a photographic plate or film to render fine detail is known as its resolving power. It is usually found by photographing a series of gratings of alternate parallel transparent and opaque lines, each line of a width equal to the space between the lines. The grating constant, (width of line plus width of space), is variable for different line groups over a relatively wide range. Resolving power is specified by stating the number of lines per mm resolvable by the material.[1,2]

Resolving power depends upon exposure, development time, the developing solution, the spectrum composition of the exposing radiation, and the contrasts in the test object. The values of resolving power given are for the optimal exposure values and optimal time of development in a particular developing solution (laboratory pyrogallol). The exposing radiation used had a spectral composition close to that of average daylight and the contrast between the elements of the test object was very high (greater than 10,000).

Sharpness. The sharpness characteristics of a photographic material is defined as the differential of density (D) with respect to distance (s) in a direction perpendicular to the edge of the image; sharpness (S) $= dD/ds$, where s is expressed in microns (0.001 mm).

Images used are obtained by making a contact print of a very carefully prepared knife edge. The exposing radiation is carefully collimated and incident normal to the surface.

Sharpness of the developed image depends upon the extent to which development is carried and this is specified by one value of gamma (γ), $dD/d \log E$. It is dependent upon the quality of radiation. The values given in the table were obtained by exposure to light, approximately equivalent to average daylight, and the exposure was so adjusted that development to a gamma of unity in pyrogallol at 20°C gave an image density of unity. These values of sharpness express the diffuse-density gradient (dD/ds) of the straight line portion of the sharpness curve obtained by plotting diffuse density (D) as a function of the distance (s) from the geometrical edge of the image.

Astro gamma. Astro gamma is defined as the coefficient (b) of $\log_{10} E$ in the Scheiner equation, which gives the relation between the diameter (D) of a stellar image and the exposure (E).

$$D = a + b \log_{10} E$$

Since exposure (E) = intensity (I) $\times$ time (t) this equation offers a means of determining the relative brightness of stars by measurement of the diameter of the stellar images obtained under known conditions of exposure and development.

In the table are given values of astro gamma for a group of typical photographic materials. These values were determined by photographing with a highly corrected lens, using a magnification of 0.05, a circular aperture (diameter of 0.56 mm). Exposing radiation was of daylight quality, and intensity was so adjusted that an exposure of 1 second was just above the threshold value. Keeping the intensity factor constant, the exposure time was increased by consecutive powers of 2 from 1 to 512 seconds. The exposed plates were developed to a gamma of unity in standard pyrogallol at 20°C.

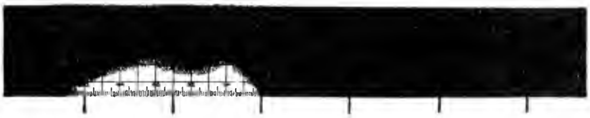
[1] Mees, Proc. Roy. Soc. (London), 83. 10, 1909.
[2] Ross, Physics of the developed photographic image, New York, Van Nostrand, 1924.

TABLE 370.—Resolving Power, Sharpness, and Astro Gamma

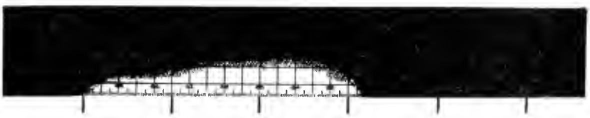
Material	Resolving Power	Sharpness	Astro gamma
Motion picture film extra fast	50	0.080	35
Motion picture film normal	55	.085	35
Motion picture film panchromatic	50	.080	35
Motion picture film positive	80	.120	25
Portrait extra fast	50	.065	40
Portrait normal	60	.070	50
Amateur film	65	.090	40
"Focal plane" plate	55	.080	45
Commercial ordinary	65	.092	35
Commercial orthochromatic	65	.097	40
Commercial panchromatic	60	.085	37
Process ordinary	90	.130	25
Process panchromatic	75	.110	30
Lantern slide plate	100	.140	20

TABLE 371.—Spectrographs Showing Relative Spectrum Sensitivity of Various Plates and Films

Ordinary, blue sensitive.



Orthochromatic, blue and green sensitive.



Panchromatic.

Dicyanine sensitized.

Kryptocyanine sensitized.

Neocyanine sensitized.

(See following page)

TABLE 372.—Spectrum Sensitivity of Photographic Materials

The spectrum distribution of sensitivity may be shown qualitatively by wedge spectrograms. These (see preceding page) are made with a spectrograph over whose slit is mounted a wedge of neutral gray glass, the transmission of which increases logarithmically from the thin to the thick end. The boundary of the exposed area outlines approximately a curve which is the resultant of the *spectral sensitivity* function of the material and the *spectral distribution of energy* in the radiation emitted by the source illuminating the slit of the instrument. The source used is an acetylene flame operating at a color temperature of 2360°K. All plates had the same exposure. By the application of a correction based on the spectral emission of a black body at 2360°K., an approximation to the actual spectral sensitivity of these materials may be obtained. The neutral glass wedge, while fairly nonselective in absorption for radiation of wave lengths longer than 450 mμ, increases in density for radiation of wave lengths shorter than 450 mμ. The apparent falling off in sensitivity at wave lengths less than 450 mμ is therefore due to excessive absorption of the neutral wedge rather than to a decrease in the spectral sensitivity of the materials. (Mees, Journ. Franklin Inst., 201, 525, 1926. Walters and Davis, Bur. Standards Bull., 17, 353, 1921.)

Note: Photo plates for spectroscopy and astronomy. Mees, Journ. Opt. Soc. Amer., 21, 753, 1931.

TABLE 373.—Relative Photographic Efficiency of Illuminants

C = luminous efficiency of source (lumen/watt). E_r = relative photographic efficiency of source evaluated on basis of equal visual intensities, sunlight = 100%. E_e = relative photographic efficiency of source evaluated on basis of equal energy consumption by the source, sunlight = 100%. (Jones, Hodgson, and Huse. Trans. Illum. Eng. Soc., 10, 963, 1915.)

Source	C	Photographic material					
		Ordinary		Orthochromatic		Panchromatic	
		E_r	E_e	E_r	E_e	E_r	E_e
Sun	150	100	100	100	100	100	100
Sky		181		155		130	
Acetylene	.7	30	.14	44	.21	52	.24
Acetylene (screened)*	.07	81	.037	85	.040	89	.042
Pentane	.45	18	.053	28	.086	42	.13
Mercury arc in quartz	40.0	600	158	500	132	367	99
Mercury arc in nultra glass	35.0	218	50	195	46	165	39
Mercury arc in crown glass	37.0	324	79	275	68	249	62
Carbon arc, ordinary	12.0	126	10	112	9	104	8.5
Carbon arc, white flame	29.0	257	52	234	45	215	4.2
Carbon arc, enclosed	9.0	175	11	177	11	165	10
Carbon arc, "Aristo"	12.0	796	62	1070	86	744	60
Magnetite arc	18.0	106	12	115	14	82	10
Carbon glow lamp	2.4	23	.37	32	.52	42	.68
Carbon glow lamp	3.2	25	.51	35	.74	45	.95
Tungsten (vacuum)	8.0	33	1.7	41	2.2	50	2.7
Tungsten (vacuum)	9.9	37	2.4	45	3.0	53	3.5
Tungsten (gas filled)	16.6	56	6.1	62	6.8	70	7.7
Tungsten (gas filled)	21.6	64	8.9	68	9.8	76	11
Tungsten (C_3)	8.9	95	5.5	87	5.2	95	5.6
Tungsten (C_3)	11.0	108	7.8	99	7.3	106	7.9
Mercury vapor	23.0	316	47	354	54.2	273	42.0

* Screened with Wratten No. 79 filter.

TABLE 374.—Variation of Resolving Power with Plate and Developer

The resolving power is expressed as the number of lines per millimeter which is just resolvable, the lines being opaque and separated by spaces of the same width. The developer used for the comparison of plates was Pyro-soda; the plate for the comparison of developers, Seed Lantern. The numbers are all in the same units. Huse, J. Opt. Soc. America, July, 1917.

Plate.	Albumen.	Resolution.	Process.	Lantern.	Medium speed.	High speed.
Resolving power......	125	81	67	62	35	27

Developer.	Resolving power.	Developer.	Resolving power.	Developer.	Resolving power.
Pyro-caustic.....	77	Pyrocatechin	62	Amidol	51
Glycin...........	69	Pyro-metol..........	62	Process hydroquinone..	50
Hydroquinone....	64	Eikon.-hydroquinone ..	61	Ortol	49
Pyro............	64	Ferrous oxalate.......	61	Rodinal	49
MQ_{25}............	64	Caustic hydroquinone..	57	X-ray powders........	49
Metol...........	63	Eikonogen...........	57	Edinol	47
Nepera..........	62	Kachin	54		

TABLE 375.—Relative Intensification of Various Intensifiers

Bleaching solution.	Blackening solution.	Reference	Intensification.
Mercuric bromide................	Amidol developer	$HgBr_2$ solution (Monckhoven sol. A).*	1.15
Mercuric chloride................	Ammonia	Bleach according to Bennett; blackener.*	1.15
Potassium bichromate + hydrochloric acid..................	Amidol developer	Piper.*	1.45
Mercuric iodide..................	Schlippe's salt	Debenham, B. J.,† p. 186, '17.	2.50
Lead ferricyanide.................	Sodium sulphide	B. J. Almanac.*	2.28
Uranium formula..................	—	B. J. Almanac.*	3.50
Potassium permanganate + hydrochloric acid..................	Sodium stannate		2.05
Cupric chloride..................	Sodium stannate	Desalme, B. J.,† p. 215, '12.	1.93
Potassium ferricyanide + potassium bromide..................	Sodium sulphide	Ordinary sepia developer.	1.33
Mercuric iodide..................	Paraminophenol developer	HgI_2 according to Bennett.	1.23

See Nietz and Huse, J. Franklin Inst. March 3, 1918.
* B. J. Almanac, see annual Almanac of British Journal of Photography.
† B. J. refers to British Journal of Photography.

TABLE 376.—Reflection and Transmission by Photographic Plates

Plates used, Eastman 40, emulsion, 2637; for red, green, and blue light, Wratten filters customarily used for 3-color work, see Wratten light filters, Eastman Kodak Co.; for "actinic" data, average transmission of plate for a band of wave length corresponding to the sensitivity curve of the plate was obtained by photographing the transmission of light upon a plate of the same type. (McRae, R. C. Tolman, Journ. Opt. Soc. Amer., 20, 565, 1930.)

	Red	Green	Blue	"Actinic"
Per cent reflected.......	58	57	25	28
" " transmitted ...	43	34	9	15
" " absorbed	—1	9	66	57

For "Instruments and Methods used for Measuring Spectral Light Intensities by Photography," see George R. Harrison, Journ. Opt. Soc. Amer., 19, 267, 1929. This reference contains bibliography of subject matter.

The Eberhard effect is due to the fact that when a heavily exposed area of an emulsion is being developed, a large quantity of soluble bromide is set free which acts as a restrainer and slows the development of surrounding regions.

TABLE 377

WAVE LENGTHS OF FRAUNHOFER LINES

For convenience of reference the values of the wave lengths corresponding to the Fraunhofer lines usually designated by the letters in the column headed "index letters," are here tabulated separately. The values are in International Angstrom units. The table is for the most part taken from St. John's revision of Rowland's table of standard wave lengths (1928).

Index letter	Line due to—	Wave length in centimeters × 10^8	Index letter	Line due to—	Wave length in centimeters × 10^8
[A]	O	7621	[G]	Fe	4307.914
	O	7594		Ca	4307.749
[a]	....	7164.449	[g]	Ca	4226.742
[B]	O	6869.955	[h] or H_δ	H	4101.750
[C] or H_α	H	6562.816	[H]	Ca	3968.494
a	O	6278.101	[K]	Ca	3933.684
[D_1]	Na	5895.944	[L]	Fe	3820.438
[D_2]	Na	5889.977	[M]	Fe	3727.636
[D_3]	He	5875.618	[N]	Fe	3581.210
[E_1]	Fe	5270.390	[O]	Fe	3441.020
	Ca	5270.270	[P]	Ti	3361.194
[E_2]	Fe	5269.557	[Q]	Fe	3286.773
[b_1]	Mg	5183.621	[R]	Ca	3181.277
[b_2]	Mg	5172.700		Ca	3179.343
[b_3]	Fe	5169.052	[S_1] [S_2]	Fe	3100.683
	Fe	5168.910		Fe	3100.326
[b_4]	Fe	5167.510		Fe	3099.943
	Mg	5167.330	[s]	Fe	3047.623
[F] or H_β	H	4861.344	[T]	Fe	3021.067
[d]	Fe	4383.559	[t]	Fe	2994
[G'] or H_γ	H	4340.477	[U]	Fe	2948
[f]	Fe	4325.777			

The solar intensities of the lines of the 4th column are: G, 6, 3; g, 20; h, 40; H, 700; K, 1000; L, 25; M, 4; N, 30; O, 15; P, 3; Q, 7; R, 3, 5; S, 3, 4, 6; s, 20; T, 3.

STANDARD WAVE LENGTHS

TABLE 378.—Primary Wave-Length Standard. Definition of Angstrom

The wave length of the red cadmium line in dry air, 15° C (hydrogen thermometer), 760 mm of Hg pressure, gravity at latitude 45° being 980.67, shall be taken as

6438.4696 Angstroms

The cadmium light shall be produced by a high-voltage, internal electrode vacuum tube, volume greater than 25 cm^3, exciting current less than 0.05 amp., temperature not higher than 320° C. When connected to usual high voltage the tube shall be nonluminous at room temperatures. (Trans. Int. Union Solar Res., 2, 20, 1907. Trans. Int. Astron. Union, 2, 40, 1925.)

TABLE 379.—International Secondary Standards. Iron Arc Lines

The wave lengths are observed in air at 15° C, 760 mm pressure. The arc should have its anode below, consisting of a bead of iron oxide supported in the hollowed upper end of a rod of iron or copper at least 10 or 15 mm diameter. The cathode is to be a rod of steel 6 or 7 mm in diameter having a massive cylinder of brass or copper fitted close to the end, so that only 2 or 3 mm of the rod protrude. The arc is to be not less than 12 mm long, preferably 15 to 18 mm. The line voltage may be 110 or more and the current strength 5 amperes or less. A horizontal central cone at right angles to the axis of the arc not exceeding 1.5 mm in vertical dimension is to be used. (See Trans. Int. Astron. Union, 3, 11, 1929, for further details.)

The wave lengths are in International Angstroms. They have been newly referred to the red cadmium line. The results indicate the need of a slight revision of the standards formerly adopted upon which all wave lengths in the International System hitherto made have been based. The corrections to be applied to the previously adopted standards and measures based upon them to reduce them to the new standards are:

λ 3370. to λ 4000. A.	—0.001 A.
4005 to 5506	—0.002
6027 to 6085	—0.005
6127 to 6260	—0.006
6297 to 6430	—0.007
6475 to 6609	—0.008
6663 to 6750	—0.009

Significance of small letters in following table: (a) Low-temperature lines; always sharp and symmetrical; energy level low; pressure displacement small; limits of upper terms for Fe 19,700 to 32,500 cm^{-1}. (b) Symmetrical under pressure, but showing a slight dissymmetry toward red, or an unsymmetrical reversal under high pressure and in the high-current arc; energy level and pressure displacement medium; limits of upper terms for Fe 32,500 to 41,500 cm^{-1}. (d) High-temperature lines; asymmetrical toward violet; pole-effect large and negative; energy level high; pressure displacement large; limits of upper terms for Fe 53,500 to 55,000 cm^{-1}. (Carnegie Publ. 396, Mt. Wilson Obs.) The letters r and R indicate narrow and wide reversals, respectively, as observed by Burns.

STANDARD WAVE LENGTHS (*Continued*)

TABLE 379 (*continued*).—International Secondary Standards. Iron Arc Lines

Measured in air at 15°C, 760 mm

λ_{Fe}	Int.	Class	λ_{Fe}	Int.	Class	λ_{Fe}	Int.	Class	λ_{Fe}	Int.	Class
3370.787	6		3797.517	5	b	4107.492	5	b	4494.568	5	b
3401.522	4	b	3798.513	6r	b	4114.449	4	b	4517.530	2	d?
3465.863	6R	a	3799.549	6r	b	4118.549	6	b	4528.619	7	b
3476.705	5r	a	3805.345	6	b	4121.806	2	b	4531.152	5	b
3497.844	5r	a	3815.842	7R	b	4127.612	4	b	4547.851	3	b
3513.820	5	b	3824.444	6R	a	4132.060	7	b	4592.655	4	b
3521.264	5r	b	3825.884	8R	b	4134.681	5	b	4602.944	4	b
3558.518	5r	b	3827.825	6R	b	4143.871	7	b	4647.437	4	b
3565.381	6R	b	3834.225	7R	b	4147.673	4	b	4667.459	4	b?
3576.760	4		3839.259	5	a?	4156.803	4	b	4678.852	5	b?
3581.195	8R	b	3840.439	6R	b	4170.906	2	b	4691.414	4	b?
3584.663	5		3841.051	6R	b	4175.640	4	b	4707.281	5	d
3585.320	6r	b	3843.259	5	b	4184.895	4	b	4710.286	3	b
3586.114	5		3846.803	5	b?	4202.031	7r	b	4733.596	3	b
3589.107	4	b	3849.969	5	b	4203.987	3	b	4741.533	3	b
3608.861	6R	b	3850.820	5	b	4213.650	2	b	4745.806	3	b
3617.788	6	b	3856.373	6R	a	4216.186	4	a	4772.817	3	b
3618.769	6R	b	3859.913	7R	a	4219.364	5	b	4786.810	3	b
3621.463	6		3865.526	6R	b	4250.790	8	b	4789.654	3	b
3631.464	6R	b	3867.219	3	b	4267.830	2	b	4859.748	5	d
3647.844	6R	b	3872.504	6r	b	4271.764	8r	b	4878.218	5	d
3649.508	6		3873.763	4	b	4282.416	6	a	4903.317	5	d
3651.469	6	b	3878.021	6r	b	4285.445	2	b	4918.999	8	d
3669.523	6	b	3878.575	6R	a	4294.128	6	b	4924.776	3	b
3676.314	6	b	3886.284	7R	a	4298.040	2		4939.690	3	a
3677.630	6		3887.051	6r	b	4305.455	2	b	4966.096	5	d
3679.915	5r	a	3888.517	7	b	4307.906	8r	b	4994.133	3	a
3687.458	6R	b	3895.658	5r	a	4315.087	5	a	5001.871	5	d
3695.054	3	b	3899.709	6r	a	4325.765	9r	b	5012.071	4	a
3704.463	5	b	3902.948	7r	b	4337.049	5	b	5041.759	4	a
3705.567	6R	a	3906.482	5r	a	4352.737	4	a	5049.825	5	b
3719.935	8R	a	3907.937	3	b	4358.505	2	b	5051.636	4	a
3722.564	6R	a	3917.185	5	b	4369.774	3	b	5083.342	4	a
3724.380	6	b?	3920.260	6r	a	4375.932	5	a	5110.414	4	a
3727.621	6R	b	3922.914	6R	a	4383.547	10R	b	5123.723	4	a
3732.399	6	b	3927.922	6r	a	4390.954	3	b	5127.363	3	a
3733.319	6R	a	3930.299	7R	a	4404.752	8r	b	5150.843	4	a
3734.867	9R	b	3935.815	4	b	4408.419	4	b	5167.491	8	a
3737.133	7R	a	3940.882	4	b	4415.125	8r	b	5168.901	3	a
3738.308	4	b	3942.443	3	b	4422.570	4	b	5171.599	7	a
3748.264	6R	a	3948.779	4	b	4427.312	5	a	5198.714	4	b
3749.487	8R	b	3956.681	4	b	4430.618	4	b	5202.339	5	b
3758.235	7R	b	3966.066	7	b	4442.343	5	b	5216.278	5	a
3760.052	5	b	3967.423	4	b	4443.197	3	b	5227.192	8	a
3763.790	6R	b	3969.261	7r	b	4447.722	5	b	5242.495	3	a?
3765.542	6	b	4005.246	7	b	4454.383	3	b	5250.650	3	b
3767.194	6R	b	4014.534	4	b	4459.121	5	b	5270.360	8	a
3787.883	6R	b	4045.815	8R	b	4461.654	4	a	5307.365	4	a
3790.095	4	b	4066.979	4	b	4466.554	5	b	5328.534	4	a
3795.004	6r	b	4067.275	3	b	4489.741	3	a	5341.026	5	a

STANDARD WAVE LENGTHS (*concluded*)

TABLE 379 (*concluded*).—International Secondary Standards. Iron Arc Lines

λ_{Fe}	Int.	Class	λ_{Fe}	Int.	Class	λ_{Fe}	Int.	Class	λ_{Fe}	Int.	Class
5371.493	7	a	5506.782	4	a	6065.487	4	b	6393.605	5	b
5397.131	6	a	5569.625	5	d	6136.620	4	b	6421.355	4	b
5405.778	6	a	5572.849	5	d	6137.696	4	b	6430.851	5	b
5429.699	6	a	5586.763	6	d	6191.562	5	b	6494.985	5	b
5434.527	6	a	5615.652	6	d	6230.728	5	b	6546.245	5	b
5446.920	6	a	5624.549	5	d	6252.561	4	b	6592.919	5	b
5455.613	6	a	5658.826	4	d	6265.140	3	b	6663.446	4	b
5497.519	4	a	5662.525	3	d	6318.022	4	b	6677.993	5	b
5501.469	4	a	6027.057	2	b	6335.335	4	b			

(Values taken from Trans. Int. Astron. Union, 3, 86, 1929.)

TABLE 380.—Computed Wave Lengths of Iron Arc Lines

Based on Term Values derived from Table 379. λs in air, 15°C, 760 mm.

λ_{Fe}	Int.	Class	λ_{Fe}	Int.	Class	λ_{Fe}	Int.	Class	λ_{Fe}	Int.	Class
2858.896	4	b	2966.898	6R	b	3083.742	4r	b	3161.370	2	d
2874.172	7	b	2983.571	4r	b	3091.577	4r	b	3171.343	4	d
2912.158	8	b	3021.073	6R	b	3100.303	4r	b	3180.756	4	a
2929.007	7	b	3037.389	5r	b	3100.666	4r	b	3184.895	4	a
2936.904	7r	b	3047.605	6r	b	3116.632	5	b	3199.501	6	a
2941.342	8	b	3057.448	5r	b	3125.651	6	b	3226.714	1	a
2947.876	5r	b	3059.086	5r	b	3129.333	4	d	3229.121	4	a
2953.940	5r	b	3067.245	5r	b	3134.111	5	b	3236.223	5	a
			3075.719	5r	b	3143.243	2	a			

(For significance of designations see preliminary remarks to next preceding table. Values taken from same source, 3, 92, 1929. The following actual measures of the lines of this table may be compared with the above figures: Buisson and Fabry, 1908, 2874.176; 2941.347; 3075.725; 3125.661. Burns, 1915, 2941.348; 3075.726; 3083.747; 3091.582; 3116.638; 3125.665; 3129.340; 3134.115; 3184.900; 3199.527; 3236.227.)

TABLE 381.—Neon Wave Lengths

The lines starred in the following table were adopted in 1922 and 1925 as standards by the International Astronomical Union.

Intensity	Wave length	Intensity	Wave length	Intensity	Wave length	Intensity	Wave length	Intensity	Wave length
5	3369.904	5	3515.192	2	5820.155	4	6217.280	5	6717.043
6	3417.906	8	3520.474	10	5852.488	7	6266.495	8	6929.468
6	3447.705	4	3593.526	6	5881.895	4	6304.789	3	7024.049
6	3454.197	4	3593.634	8	5944.834	8	6334.428	9	7032.413
5	3460.526	5	3600.170	4	5975.534	8	6382.991	3	7059.111
4	3464.340	5	3633.664	4	6029.997	10	6402.245	5	7173.939
5	3466.581	8	5330.779	7	6074.338	9	6506.528	8	7245.167
6	3472.578	7	5341.096	8	6096.163	4	6532.883	6	7438.902
4	3498.067	6	5400.562	9	6143.062	5	6598.953	5	7488.885
4	3501.218	4	5764.419	5	6163.594	8	6678.276	5	7535.784

International Units (Angstroms). Burns, Meggers, Merrill, Bull. Bur. Stds. 14, 765, 1918.

TABLE 382

STANDARD SOLAR WAVE LENGTHS. INTERNATIONAL ANGSTROMS

Adopted at the Leyden Meeting of the International Astronomical Union.

See Trans. Int. Astron. Union. 3, 93, 1929.

The solar wave lengths in the Rowland Revision by St. John (and others) are based upon the former arc standards and require the folllwing corrections to reduce them to the scale of the following adopted lines:

λ 3592 to λ 5625 A.	−0.002 A.	at λ 6350 A.	−0.007 A.
at 2850	− .003	6500	− .008
5950	− .004	6700	− .009
6050	− .005	6850	− .011
6200	− .006	7100	− .014

In the following table the + sign following the designation of an element indicates the state of ionization; an indication like Fe−, solar line too strong to be due to iron alone; Fe, Co, coincidences of like order; Fe Co, coincidence closer for preceding element; Fe-Co, Fe line to the red, Co, to the violet; an italicized element indicates predominence of that element.

λ_{solar}	Elements	Int.	λ_{solar}	Elements	Int.	λ_{solar}	Elements	Int.
3592.027	V+	2	4079.843	Fe	3	4439.888	Fe	1
3635.469	*Ti*Fe	4	4082.943	*Mn*V	4	4451.588	Mn	3
3650.538		2	4091.557	Fe	3	4454.388	Fe	3
3672.712	Fe−	3	4094.938	Ca	4	4459.755	Cr−*V*	1
3695.056	Fe	5	4107.492	Fe	5	4470.485	Ni	2
3710.292	Y+	3	4120.212	Fe	4	4481.616	Fe	1
3725.496	Fe	3	4136.527	Fe	4	4502.221	Mn	2
3741.065	Ti	4	4139.936	Fe	6	4508.289	Fe+	4
3752.418	Fe	3	4154.814	Fe	4	4512.741	Ti	3
3760.537	Fe	4	4163.654	*Ti*+Cr−Fe	4	4517.534	Fe	3
3769.994	Fe	4	4168.620	Fe	2	4525.146	Fe	5
3781.190	Fe	3	4178.859	Fe+	3	4531.631	Fe	2
3793.876	CrFe	2	4184.900	*Fe*, Cr	4	4534.785	Ti	4
3804.015	Fe	3	4191.683	Fe	3	4541.523	Cr*Fe*+	2
3821.187	Fe	4	4198.638	V−*Fe*	3	4547.853	Fe	3
3836.090	Ti+	2	4208.608	Fe	3	4548.770	Ti	2
3843.264	Fe	4	4220.347	Fe	3	4550.773	Fe	2
3897.458	Fe	2	4233.612	Fe	6	4563.766	Ti+	4
3906.752	FeV	4	4241.123	Fe−	2	4571.102	Mg	5
3916.737	Fe	5	4246.837	Sc+	5	4571.982	Ti+	6
3937.336	Fe	3	4257.661	Mn	2	4576.339	Fe+	2
3949.959	Fe	5	4266.968	Fe	3	4578.559	Ca	3
3953.861	Fe−	3	4267.680	Fe	2	4587.134	Fe	2
3960.284	Fe	4	4282.412	Fe	5	4589.953	Ti+	3
3963.691	Cr	3	4291.472	Fe	2	4598.125	Fe	3
3977.747	Fe	6	4318.659	*Ca*Ti	4	4602.008	Fe	3
3991.121	Cr−Zr+	3	4331.651	Ni	2	4602.949	Fe	6
4003.769	FeCe+−Ti	3	4337.925	Ti+	4	4607.654	Fe	4
4016.423	Fe	2	4348.947	Fe	2	4617.276	Ti	3
4029.642	*Fe*−Zr+	5	4365.904	Fe	2	4625.052	Fe	5
4030.190	Fe	2	4389.253	Fe	2	4630.128	Fe	4
4037.121		2	4398.020	Y+	1	4635.853	Fe	2
4053.824	Ti+Fe	3	4416.828	Fe+	2	4637.510	Fe	5
4062.447	Fe	5	4425.444	Ca	4	4638.017	Fe	4
4073.767	*Fe*Ce+	4	4430.622	Fe	3	4643.470	Fe	4

STANDARD SOLAR WAVE LENGTHS. INTERNATIONAL ANGSTROMS

λ_{solar}	Elements	Int.	λ_{solar}	Elements	Int.	λ_{solar}	Elements	Int.
4647.442	Fe	4	5415.210	Fe	5	6003.022	Fe	6
4656.474	Ti	3	5432.955	Fe	2	6008.566	Fe	6
4664.794	−CrNa?	3	5445.053	Fe	4	6013.497	Mn	6
4678.172		3N	5462.970	Fe	3	6016.647	Mn	6
4678.854	Fe	6	5473.910	Fe	3	6024.068	Fe	7
4683.567	Fe	3	5487.755	Fe	3	6027.059	Fe	4
4690.144	−Fe	4	5501.477	Fe	5	6042.104	Fe	3
4700.162		4	5512.989	Ca	4	6065.494	Fe	7
4704.954	Fe	4	5525.552	Fe	2	6078.499	Fe	5
4720.999	Fe	2	5534.848	Fe+	2	6079.016	Fe	2
4728.552	Fe	4	5546.514	Fe	2	6082.718	Fe	1
4733.598	Fe	4	5590.126	Ca	3	6085.257	Ti−Fe	2
4735.848	Fe	3	5601.286	Ca	3	6086.288	Ni	1
4736.783	Fe	6	5624.558	Fe	4	6089.574	Fe	1
4741.535	Fe	3	5641.448	Fe	2	6090.216	V	2
4745.807	Fe	4	5655.500	Fe	2	6093.649	Fe	3
4772.823	Fe	4	5667.524	Fe	2	6096.671	Fe	3
4788.765	Fe	3	5679.032	Fe	3	6102.183	Fe	6
4789.658	Fe	3	5690.433	Si	3	6102.727	Ca	9
4802.887	Fe	2	5701.557	Fe	4	6111.078	Ni	2
4824.143	Cr+−Fe	3	5731.772	Fe	4	6116.198	Ni	4
4832.719	Ni−*Fe*	3	5741.856	Fe	2	6122.226	Ca	10
4839.551	Fe	3	5752.042	Fe	4	6127.912	Fe	3
4939.694	Fe	3	5760.841	Ni	2	6128.984	Ni	1
4983.260	Fe	3	5805.226	Ni	4	6136.624	Fe	8
4994.138	Fe	3	5809.224	Fe	4	6137.002	Fe	3
5002.798	Fe	2	5816.380	Fe	5	6137.702	Fe	7
5014.951	Fe	3	5853.688	Ba+	5	6141.727	*Ba*+−Fe	7
5028.133	Fe	2	5857.459	Ca	8	6145.020		2
5079.745	Fe	4	5859.596	Fe	5	6149.249	Fe+	2
5090.782	Fe	5	5862.368	Fe	6	6151.623	Fe	4
5109.657	Fe	2	5866.461	Ti	3	6154.230	Na	2
5150.852	Fe	4	5867.572	Ca	2	6157.733	Fe	5
5159.065	Fe	2	5892.883	Ni	4	6161.295	Ca	4
5198.718	Fe	3	5898.166	Atm.wv	4	6162.180	Ca	15
5225.534	Fe	2	5905.680	Fe	4	6165.363	Fe	3
5242.500	Fe	2	5916.257	Fe	3	6166.440	Ca	5
5253.468	Fe	2	5919.054	Atm.wv	5	6169.564	Ca	7
5273.389	*Fe*−Nd+	2	5919.644	Atm.wv	7	6170.516	*Fe*−Ni	6
5288.533	Fe	2	5927.797	Fe		6173.341	Fe	5
5300.751	Cr	2	5930.191	Fe	6	6175.370	Ni	3
5307.369	Fe	3	5932.092	Atm.wv	5	6176.816	Ni	5
5322.049	Fe	3	5934.665	Fe	5	6180.209	Fe	5
5332.908	Fe	4	5946.006	Atm.wv	3	6186.717	Ni	2
5348.326	Cr	4	5952.726	Fe	4	6187.995	Fe	4
5365.407	Fe	3	5956.706	Fe	4	6191.571	Fe	9
5379.581	Fe	3	5975.353	Fe	3	6200.321	Fe	6
5389.486	Fe	3	5976.787	Fe	4	6213.437	Fe	6
5398.287	Fe	3	5983.688	Fe	5	6215.149	Fe	5
5409.799	Cr	4	5984.826	Fe	6	6216.358	V	1

STANDARD SOLAR WAVE LENGTHS. INTERNATIONAL ANGSTROMS

λ_{solar}	Elements	Int.	λ_{solar}	Elements	Int.	λ_{solar}	Elements	Int.
6219.287	Fe	6	6301.508	Fe	7	6482.809	Ni	1
6226.740	Fe	1	6302.499	Fe	5	6493.788	Ca	6
6229.232	Fe	1	6302.764	Atm.O_2	2	6494.994	Fe	8
6230.736	*Fe*−V	8	6305.810	Atm.O_2	2	6498.945	Fe	1
6232.648	Fe	3	6306.565	Atm.O_2	2	6499.654	Ca	4
6240.653	Fe	3	6309.886	Atm.O_2	2	6516.083	Fe+	2
6244.476		2	6315.314	Fe	2	6518.373	Fe	2
6245.620	Sc+	1	6315.814	Fe	1	6569.224	Fe	5
6246.327	Fe	8	6318.027	Fe	6	6592.926	Fe	6
6247.562	Fe+	2	6322.694	Fe	4	6609.118	Fe	3
6252.565	Fe	7	6327.604	Ni	2	6643.638	Ni	5
6254.253	Fe	5	6330.852	Fe	2	6677.997	Fe	5
6256.367	*Fe*Ni	6	6335.337	Fe	6	6717.687	Ca	5
6258.110	Ti	2	6336.830	Fe	7	6810.267	Fe	3
6258.713	Ti	3	6344.155	Fe	4	6858.155	Fe	2
6265.141	Fe	5	6355.035	Fe	4	6870.946	Atm.O_2	8
6270.231	Fe	3	6358.687	Fe	6	6879.928	Atm.O_2	6
6279.101	Atm.O_2	3	6378.256	Ni	2	6918.122	Atm.O_2	9
6279.896	Atm.O_2	2	6380.750	Fe	4	6919.002	Atm.O_2	9
6280.393	Atm.O_2	2	6393.612	Fe	7	6923.302	Atm.O_2	9
6280.622	Fe	3	6400.009	Fe	8	6924.172	Atm.O_2Cr	9
6281.178	Atm.O_2	1	6400.323	Fe	2	6928.728	Atm.O_2	4
6281.956	Atm.O_2	2	6408.026	Fe	5	6934.422	Atm.O_2	2
6283.796	Atm.O_2	1	6411.658	Fe	7	6959.452	Atm.wv	3
6289.398	Atm.O_2	1	6419.956	Fe	4	6961.260	Atm.wv	4
6290.221	Atm.O_2	2	6421.360	Fe	7	6978.862	Fe	2
6292.162	Atm.O_2	2	6430.856	Fe	5	6986.579	Atm.wv	3N
6292.958	Atm.O_2	3	6449.820	Ca	6	6988.986	Atm.wv	3
6295.178	Atm.O_2	3	6455.605	Ca	2	7022.957	Fe	2
6295.960	Atm.O_2	3	6456.391	Fe+	3	7023.504	Atm.wv	2
6297.799	Fe	5	6471.668	Ca	5	7027.478	Atm.wv	2
6299.228	Atm.O_2	3	6475.632	Fe	2	7034.910	−Fe	2N
						7122.206	Ni	4

PROVISIONAL ULTRA-VIOLET AND INFRA-RED SOLAR WAVE LENGTHS

Suggested at the 1928 meeting of the International Astronomical Union for further measurements leading to the use of them as standards. Trans. Int. Astron. Union, 3, 101 and 102, 1929. Wave lengths in International Angstroms.

λ_{solar}	Elements	Int.	λ_{solar}	Elements	Int.	λ_{solar}	Elements	Int.
2990.421	Fe	1	3199.528	Fe	4	3389.749	Fe	2
2998.815	Cr−	2	3210.226	Co−Fe	3	3396.982	Fe	3
3005.061	Cr	3	3217.393	Fe	2	3401.531	Fe	3
3021.067	Fe	3	3225.805	Fe	3	3412.350	Co	5
3035.745		5	3232.291	Ti+	2	3419.705	Fe	2
3046.676	Ti+	5	3243.415	Fe	1	3425.584		2
3061.825	Co	3	3254.762	Fe−V, V+	5d?	3431.587	Co	4
3070.266	Mn	3	3262.289	Fe	3	3445.126	−Fe	5
3086.788	Co	4	3273.053	Zr+	2	3450.335	Fe	5
3094.898	Fe?−	4	3278.296	Ti+	5	3455.246	Co−	5
3109.334	OH−Cr	3	3293.150	Fe	2	3462.359	Fe	1
3121.161	V+	4	3295.825	−Fe+Mn	6	3466.505	Fe	3
3126.208	Fe−V+	5	3301.226	Fe	1	3477.866	Fe−Ni	4
3140.758	CoOH−Ca	3	3318.032	Ti+	6	3485.903	Ni	5
3142.471	Fe−V+	5	3323.753	Fe	3	3509.126	Fe	2
3152.263	Ti+	5	3333.396	Co	2	3517.307	V+	3
3161.775	Ti+	3	3344.524	*Ca*−La+	2	3540.127	Fe	5
3162.571	Ti+	4	3355.231	Fe	4	3549.873	Fe	3
3170.345	Fe+Mo	2	3365.774	Ni	6	3564.127w	Fe−Co	4
3187.714	V+	2	3381.354	Fe	2	3583.340w	Fe−	5
7005.903		1	7583.796	Fe	1	8233.905	Atm.	5
7011.323	Atm. Fe	2	7676.563	Atm.	4	8252.727	Atm.	2
7052.776	Atm.	1	7677.618	Atm.	4	8272.041	Atm.	4
7068.423	Fe	2	7682.756	Atm.	3	8289.533	Atm.	4
7090.390	Fe	2	7696.868	Atm.	0	8300.406	Atm.	3
7130.925	Fe	3	7714.309	Ni	3	8327.060	Fe	2
7181.509	Atm.	2	7727.616	Ni	3	8329.682	Atm.	3
7195.044	Atm.	2	7742.722	Fe	2	8342.289	Atm.	1
7204.306	Atm.	5	7780.567	Fe	3	8357.041	Atm.	1
7216.527	Atm.	2	7797.587	Ni	2	8367.333	Atm.	2
7227.493	Atm.	3	7807.915	Fe	1	8387.783	Fe	3
7236.136	Atm.	1	7832.207	Fe	2	8426.518	Ti	0
7245.676	Atm.	2	7849.984		1	8439.583	Fe	0
7265.594	Atm.	5	7887.117	Atm.	1	8468.420	Fe, Ti	2
7303.197	Atm.	2	7901.780	Atm.	3	8514.081	Fe	1
7323.972	Atm.	1	7918.383	Si	1	8515.121	Fe	0
7326.164	Ca	0	7937.149	Fe	3	8556.795	Si?	1
7335.334	Atm.	1	7945.857	Fe	2	8582.271	Fe	1
7355.893	Cr	1	7984.343	Atm.	1	8611.813	Fe	1
7369.208	Atm.	1	8012.940	Atm.	1	8621.619	Fe	1
7383.722	Atm.	1	8034.293	Atm.	1	8648.472		2
7389.391	Fe	2	8046.056	Fe	2	8674.756	Fe	1
7393.610	Ni	2	8085.175	Fe	2	8688.642	Fe	2
7405.790	Si	1	8107.841	Atm.	1	8699.459	Fe	1
7411.158	Fe	1	8125.444	Atm.	1	8717.832		0
7422.286	Ni	1	8139.718	Atm.	2	8736.043		1
7445.755	Fe	2	8158.019	Atm.	6	8752.024	Si	1
7491.652	Fe	1	8176.976	Atm.	10	8763.974	Fe	1
7511.030	Fe	2	8186.371	Atm.	5	8793.346	Fe	1
7525.115	Ni	1	8194.835	Na	2	8806.768	Mg	4
7555.608	Ni	2	8212.132	Atm.	4	8824.233	Fe	2
7568.906	Fe	1	8223.990	Atm.	5			

TABLE 384

REDUCTION OF WAVE-LENGTH MEASURES TO STANDARD CONDITIONS

The international wave-length standards are measured in dry air at 15° C, 76 cm pressure. Density variations of the air appreciably affect the absolute wave-lengths when obtained at other temperatures and pressures. The following tables give the corrections for reducing measures to standard conditions, viz.: $\delta = \lambda_0(n_0 - n_0')(d - d_0)/d_0$ in ten-thousandths of an Angstrom, when the temperature $t°$ C, the pressure B in cm of Hg, and the wave-length λ in Angstroms are given; n and d are the indices of refraction and densities, respectively; the subscript $_0$ refers to standard conditions none, to the observed; the prime $'$ to the standard wave-length, none, to the new wave-length. The tables were constructed for the correction of wave-length measures in terms of the fundamental standard 6438.4696 A of the cadmium red radiation in dry air, 15° C, 76 cm pressure. The density factor is, therefore, zero for 15° C and 76 cm, and the correction always zero for λ = 6438 A. As an example, find the correction required for λ when measured as 3000.0000 A in air at 25° C and 72 cm. Section (*a*) of table gives $(d - d_0)/d_0 = -.085$ and for this value of the density factor section (*b*) gives the correction to λ of $-.0038$ A. Again, if λ, under the same atmospheric conditions, is measured as 8000.0000 A in terms of a standard λ' of wave-length 4000.000 A, say, the measurement will require a correction of $(0.0020 + 0.0008) = +.0028$ A. Taken from Meggers and Peters, Bulletin Bureau of Standards, 14, p. 728, 1918.

(*a*). — $1000 \times (d - d_0)/d_0$

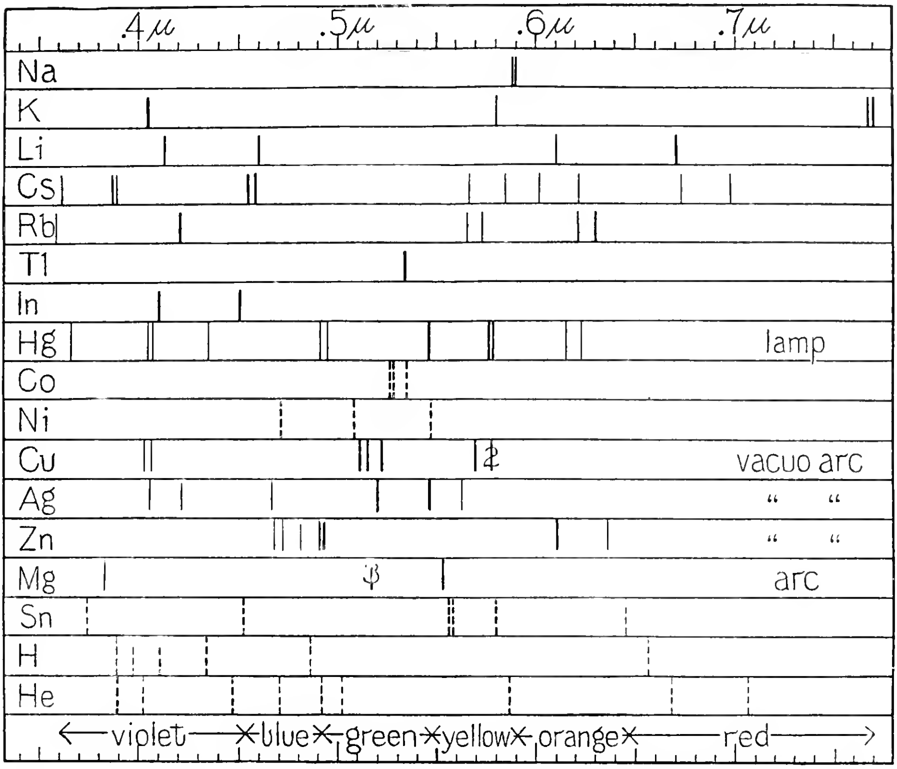
B cm	60.0	62.5	65.0	67.5	70	71	72	73	74	75	76	77	78
9° C	−192	−160	−126	−92	−59	−46	−32	−19	−5	+8	+22	+35	+48
11	−200	−167	−133	−100	−67	−53	−40	−27	−13	0	+13	+27	+40
13	−206	−172	−139	−106	−73	−60	−46	−33	−20	−7	+6	+20	+33
15	−211	−178	−145	−112	−79	−66	−53	−39	−26	−13	0	+13	+26
17	−216	−184	−151	−118	−86	−73	−60	−47	−34	−21	−8	+5	+19
19	−222	−189	−156	−124	−92	−79	−66	−53	−40	−27	−14	−1	+12
21	−227	−195	−163	−130	−98	−85	−72	−59	−46	−33	−21	−8	+5
23	−232	−200	−168	−136	−104	−91	−78	−65	−52	−40	−27	−14	−1
25	−238	−206	−174	−143	−111	−98	−85	−72	−60	−47	−34	−22	−9
27	−243	−211	−179	−148	−116	−104	−91	−78	−66	−53	−40	−28	−15
29	−248	−216	−185	−154	−122	−109	−97	−84	−72	−59	−46	−34	−21
31	−253	−222	−190	−159	−128	−116	−103	−91	−78	−66	−54	−41	−29
33	−258	−227	−196	−165	−134	−121	−109	−97	−84	−72	−59	−47	−34
35	−262	−231	−200	−170	−139	−127	−114	−102	−90	−77	−65	−53	−41

(*b*). — $\delta = \lambda_0(n_0 - n_0')(d - d_0)/d_0$, in Ten-thousandth Angstroms

$1000 \times \frac{d - d_0}{d_0}$	Wave-lengths in Angstroms.														
	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	9000	10000
	Corrections in ten-thousandth Angstroms.														
−260	−259	−166	−116	−84	−61	−44	−30	−18	−8	+1	+9	+17	+24	+37	+50
−240	−239	−154	−107	−78	−57	−41	−28	−17	−7	+1	+9	+16	+22	+35	+46
−220	−219	−141	−98	−71	−52	−37	−26	−15	−7	+1	+8	+14	+20	+32	+42
−200	−199	−128	−89	−65	−47	−34	−23	−14	−6	+1	+7	+13	+19	+29	+38
−180	−179	−115	−80	−58	−42	−30	−21	−13	−6	+1	+6	+12	+17	+26	+34
−160	−159	−102	−71	−52	−38	−27	−19	−11	−5	+1	+6	+10	+15	+23	+31
−140	−139	−90	−62	−45	−33	−24	−16	−10	−4	+1	+5	+9	+13	+20	+27
−120	−119	−77	−54	−39	−28	−20	−14	−8	−4	+0	+4	+8	+11	+17	+23
−100	−100	−64	−45	−32	−24	−17	−12	−7	−3	+0	+4	+7	+9	+14	+19
−80	−80	−51	−36	−26	−19	−14	−9	−6	−2	+0	+3	+5	+7	+12	+15
−60	−60	−38	−27	−19	−14	−10	−7	−4	−2	+0	+2	+4	+6	+9	+11
−40	−40	−26	−18	−13	−9	−7	−5	−3	−1	+0	+1	+3	+4	+6	+8
−20	−20	−13	−9	−6	−5	−3	−2	−1	−1	0	+1	+1	+2	+3	+4
0	0	0	0	0	0	0	0	0	0	−0	0	0	0	0	0
+20	+20	+13	+9	+6	+5	+3	+2	+1	+1	−0	−1	−2	−2	−3	−4
+40	+40	+26	+18	+13	+9	+7	+5	+3	+1	−0	−1	−3	−4	−6	−8

SPECTRA OF THE ELEMENTS

The following figure gives graphically the positions of some of the more prominent lines in the spectra of some of the elements. Flame spectra are indicated by lines in the lower parts of the panels, arc spectra in the upper parts, and spark spectra by dotted lines.



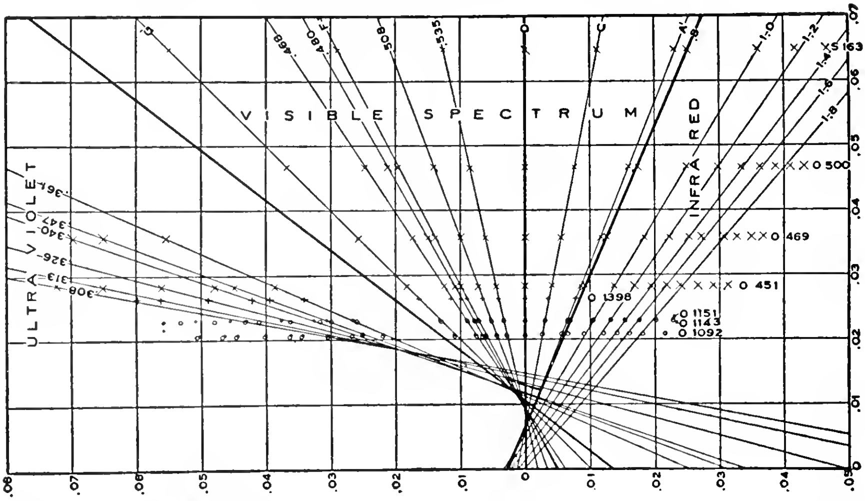
Line spectra of the elements. For bibliography see Gibbs, Rev. Mod. Phys., 4, 205, 1932.

The following wave lengths are in Angstroms

Na	5889.965	Rb	4202	Cu	4023	Mg	5168
	5895.932		4216		4063		5173
K	4044		5648		5105.543*		5184
	4047		5724		5153.251*		5529
	5802		6207		5218.202*	Sn	4525
	7668		6299		5700		5563
	7702	Tl	5351		5782.090*		5589
Li	4132	In	4102		5782.159*		5799
	4602		4511	Ag	4055		6453
	6104	Hg	4046.8		4212	H	3970
	6707.846*		4078.1		4669		4102
Cs	4555		4358.3		5209.081*		4340
	4593		4916.4		5465.489*		4861
	5664		4959.7		5472		6563
	5945		5460.742*		5623	He	3187.743†
	6011		5769.598*	Zn	4680.138*		3888.646†
	6213		5790.659*		4722.164*		4026.189†
	6724		6152		4810.535*		4471.477†
	6974		6232		4912		4713.143†
					4925		4921.929†
					6103		5015.675†
					6362.345*		5875.618†
							6678.149†
							7065.188†

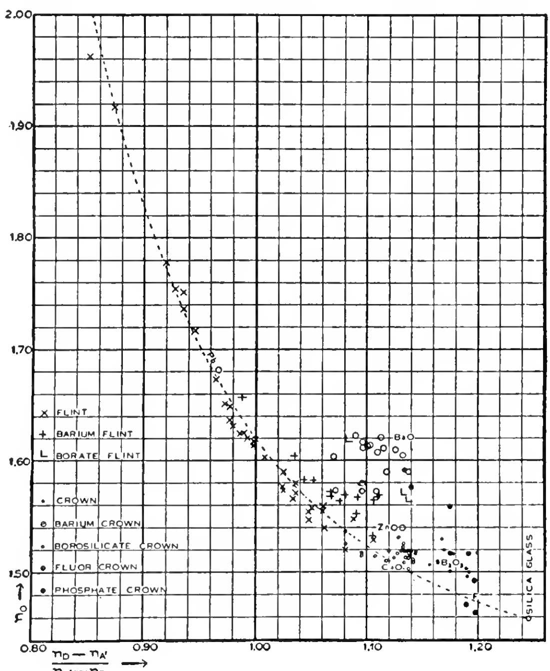
For other elements, see Kayser's Handbuch der Spectroscopie.
* Fabry and Perot. † Merrill.

TABLE 386.—Relationship between $n_X - n_D$ and $n_{G'} - n_D$



Abscissae are $n_X - n_D$, $x = 2.4$, 2.2, 2.0, 1.8, 1.6, 1.4, 1.2, 1.0, 0.8, .768, .656, .589, .535, 509, .486, .480, .468, .434, .361, .347, .327, .313, .308, .298, .288, 284, 276μ. Ordinates $n_{G'} - n_D$ for glasses measured by Rubens and Simons. Various Schott glasses included: O1092, light barium crown, ($n_D = 1.51698$); S204, borate glass, ($n_D = 1.51007$); O1143, dense barium crown, ($n_D = 1.57422$); O1151, high-dispersion crown, ($n_D = 1.52002$); O451, light flint, ($n_D = 1.57524$); O469, dense flint, ($n_D = 1.64985$); O500, dense flint, ($n_D = 1.75130$); S163, extra dense flint ($n_D = 1.88995$).

TABLE 387.—Effect of Composition on Index of Refraction



DERIVATION OF PARTIAL DISPERSIONS OF GLASS FROM n_F-n_C

(F. E. Wright, Journ. Amer. Ceramic Soc., 3, 783, 1920; Journ. Opt. Soc. Amer., 4, 148, 195, 1920; 5, 389, 1921.)

The optical constants of a glass are generally stated as the index of refraction n_D, and the partial dispersions between the A (.768μ), C (.856), D (.589), F (.486) and G′ (.434μ) lines and its ν value, $(n_D-1)/(n_F-n_C)$. The reciprocal of ν is called the average dispersive value. The following table is computed from $n_Y-n_X=a(n_F-n_C)-b$. The mean indices of refraction of two sets of glasses from which a and b were derived are:

n_A	n_C	n_D	n_F	$n_{G'}$		n_C-n_A	n_D-n_C	n_F-n_D	$n_{G'}-n_F$
1.539909	1.543168	1.545958	1.552616	1.557994	$a=$	.288936	.272167	.727833	.658443
1.588807	1.593565	1.597767	1.608201	1.616995	$b=$	.000529	.000219	—.000219	—.000843

n_F-n_C	n_C-n_A	n_D-n_C	n_F-n_D	$n_{G'}-n_F$	n_F-n_C	n_C-n_A	n_D-n_C	n_F-n_D	$n_{G'}-n_F$
.0050	.00197	.00158	.00342	.00245	.0150	.00486	.00430	.01070	.00903
55	212	172	378	278	2	492	436	1084	917
.0060	226	185	415	311	4	498	441	1099	930
65	241	199	451	344	6	504	446	1114	943
.0070	255	212	488	377	8	509	452	1128	956
75	270	226	524	410	.0160	.00515	.00457	.01143	.00969
.0080	284	240	560	442	2	521	463	1157	982
85	298	253	597	475	4	527	468	1172	996
.0090	313	267	633	508	6	533	474	1186	1009
.0100	.00342	.00294	.00706	.00574	8	538	479	1201	1022
2	348	300	720	587	.0170	.00544	.00485	.01215	.01035
4	353	305	735	600	2	550	490	1230	1048
6	359	310	750	614	4	556	495	1245	1061
8	365	316	764	627	6	561	501	1259	1075
.0110	.00371	.00321	.00779	.00640	8	567	506	1274	1088
2	377	327	793	653	.0180	.00573	.00512	.01288	.01101
4	382	332	808	666	.0185	587	525	1325	1134
6	388	338	822	679	.0190	602	539	1361	1167
8	394	343	837	693	5	616	553	1397	1200
.0120	.00400	.00349	.00851	.00706	.0200	631	566	1434	1233
2	405	354	866	719	5	645	580	1470	1266
4	411	359	881	732	.0210	660	593	1507	1298
6	417	365	895	745	5	674	607	1543	1331
8	423	370	910	759	.0220	689	621	1579	1364
.0130	.00429	.00376	.00924	.00772	5	703	634	1616	1397
2	434	381	939	785	.0230	717	648	1652	1430
4	440	387	953	798	5	732	661	1689	1463
6	446	392	968	811	.0240	746	675	1725	1496
8	452	397	983	824	5	761	689	1761	1529
.0140	.00457	.00403	.00997	.00838	.0250	775	702	1798	1562
2	463	408	1012	851	5	790	716	1834	1595
4	469	414	1026	864	.0260	804	730	1870	1628
6	475	419	1041	877	5	819	743	1907	1661
8	481	425	1055	890	.0270	.00833	.00757	.01943	.01693

TABLE 389.—Index of Refraction of Glasses (American)

Indices of refraction of optical glass made at the Bureau of Standards. Correct probably to 0.00001. The composition given refers to the raw material which went into the melts and does not therefore refer to the composition of the finished glass.

Melt	123	241	135	116	188	151	163	76
Wave-length	Ordinary crown.	Borosilicate crown.	Barium flint.	Light barium crown.	Light flint.	Dense barium crown.	Medium flint.	Dense flint.
Hg 4046.8	1.53189	1.53817	1.58851	1.59137	1.60507	1.63675	1.65788	1.69005
Hg 4078.1	1.53147	1.53775	1.58791	1.59084	1.60430	1.63619	1.65692	1.68894
H 4340.7	1.52818	1.53468	1.58327	1.58693	1.59860	1.63189	1.64973	1.68079
Hg 4358.6	1.52798	1.53450	1.58299	1.58674	1.59826	1.63163	1.64931	1.68030
H 4861.5	1.52326	1.53008	1.57646	1.58121	1.59029	1.62548	1.63941	1.66911
Hg 4916.4	1.52283	1.52967	1.57587	1.58071	1.58958	1.62492	1.63854	1.66814
Hg 5461.0	1.51929	1.52633	1.57105	1.57657	1.58380	1.62033	1.63143	1.66016
Hg 5769.6	1.51771	1.52484	1.56894	1.57473	1.58128	1.61829	1.62834	1.65671
Hg 5790.5	1.51760	1.52475	1.56881	1.57460	1.58112	1.61817	1.62815	1.65650
Na 5893.2	1.51714	1.52430	1.56819	1.57406	1.58038	1.61756	1.62725	1.65548
Hg 6234.6	1.51573	1.52297	1.56634	1.57242	1.57818	1.61576	1.62458	1.65250
H 6563.0	1.51458	1.52188	1.56482	1.57107	1.57638	1.61427	1.62241	1.65007
Li 6708.2	1.51412	1.52145	1.56423	1.57054	1.57567	1.61369	1.62157	1.64913
K 7682.0	1.51160	1.51908	1.56100	1.56762	1.57183	1.61047	1.61701	1.64405
(Percentage composition)								
SiO_2	67.0	64.2	53.7	48.0	53.9	37.0	45.6	39.0
Na_2O	12.0	9.4	1.7	2.0	1.0	—	3.4	3.0
K_2O	5.0	8.3	8.3	6.1	7.6	2.7	4.1	4.0
B_2O_3	3.5	11.0	2.7	4.0	—	5.0	—	—
BaO	10.6	6.1	14.3	29.5	—	47.0	—	—
ZnO	1.5	—	2.5	10.0	—	7.7	—	—
As_2O_3	0.4	0.4	—	1.4	0.3	—	—	—
CaO	—	1.0	—	—	2.0	—	3.0	4.0
PbO	—	—	16.7	—	35.2	—	44.0	49.0
Sb_2O_3	—	—	—	—	—	—	—	1.0

TABLE 390.—Dispersion of Glasses of Table 389

Melt.	123	241	135	116	188	151	163	76
n_D	1.51714	1.52430	1.56819	1.57406	1.58038	1.61756	1.62725	1.65548
$n_F - n_C$	0.00868	0.00820	0.01164	0.01014	0.01391	0.01121	0.01700	0.01904
$\frac{n_D - 1}{n_F - n_C} = v$	59.6	63.9	48.8	56.6	41.7	55.1	36.9	34.4
$n_D - n_F$	0.00612	0.00578	0.00827	0.00715	0.00991	0.00792	0.01216	0.01363
$n_F - n_{G'}$	0.00492	0.00460	0.00681	0.00577	0.00831	0.00641	0.01032	0.01168
$n_D - n_C$	0.00256	0.00242	0.00337	0.00299	0.00400	0.00329	0.00484	0.00541

TABLE 391.—Index of Refraction of Glasses Made by Schott and Gen, Jena

The following constants are for glasses made by Schott and Gen, Jena: n_A, n_C, n_D, n_F, $n_{G'}$, are the indices of refraction in air for $A=0.7682\mu$, $C=0.6563\mu$, $D=0.5893$, $F=0.4861$, $G'=0.4341$. $v=(n_D-1)/(n_F-n_C)$. Ultra-violet indices: Simon, Wied. Ann. 53, 1894. Infra-red: Rubens, Wied. Ann. 45, 1892. Table is revised from Landolt, Börnstein and Meyerhoffer, Kayser, Handbuch der Spectroscopie, and Schott and Gen's list No. 751, 1909. See also Hovestadt's "Jena Glass."

		O 546	O 381	O 184	O 102	O 165	S 57
Catalogue Type =		O 546	O 381	O 184	O 102	O 165	S 57
Designation =		Zinc-Crown.	Higher Dispersion Crown.	Light Silicate Flint.	Heavy Silicate Flint.	Heavy Silicate Flint.	Heaviest Silicate Flint.
Melting Number =		1092	1151	451	469	500	163
v =		60.7	51.8	41.1	33.7	27.6	22.2
Kind of Light and Wave-length.	Cd 0.2763μ	1.56759	–	–	–	–	–
	Cd .2837	1.56372	–	–	–	–	–
	Cd .2980	1.55723	1.57093	1.65397	–	–	–
	Cd .3403	1.54369	1.55262	1.63320	1.71968	1.85487	–
	Cd .3610	1.53897	1.54664	1.61388	1.70536	1.83263	–
	H $.4340\mu$	1.52788	1.53312	1.59355	1.67561	1.78800	1.94493
	H .4861	1.52299	1.52715	1.58515	1.66307	1.77091	1.91890
	Na .5893	1.51698	1.52002	1.57524	1.64985	1.75130	1.88995
	H .6563	1.51446	1.51712	1.57119	1.64440	1.74368	1.87893
	K .7682	1.51143	1.51368	1.56669	1.63820	1.73530	1.86702
	$.800\mu$	1.5103	1.5131	1.5659	1.6373	1.7339	1.8650
	1.200	1.5048	1.5069	1.5585	1.6277	1.7215	1.8481
	1.600	1.5008	1.5024	1.5535	1.6217	1.7151	1.8396
	2.000	1.4967	1.4973	1.5487	1.6171	1.7104	1.8316
	2.400	–	–	1.5440	1.6131	–	1.8286

Percentage composition of the above glasses:

O 546, SiO_2, 65.4; K_2O, 15.0; Na_2O, 5.0; BaO, 9.6; ZnO, 2.0; Mn_2O_3, 0.1; As_2O_3, 0.4; B_2O_3, 2.5.
O 381, SiO_2, 68.7; PbO, 13.3; Na_2O, 15.7; ZnO, 2.0; MnO_2, 0.1; As_2O_5, 0.2.
O 184, SiO_2, 53.7; PbO, 36.0; K_2O, 8.3; Na_2O, 1.0; Mn_2O_3, 0.06; As_2O_3, 0.3.
O 102, SiO_2, 40.0; PbO, 52.6; K_2O, 6.5; Na_2O, 0.5; Mn_2O_3, 0.09; As_2O_5, 0.3.
O 165, SiO_2, 29.26; PbO, 67.5; K_2O, 3.0; Mn_2O_3, 0.04; As_2O_3, 0.2.
S 57, SiO_2, 21.9; PbO, 78.0; As_2O_5, 0.1.

TABLE 392.—n_D, Dispersion and Density of Jena Glasses

No. and Type of Jena Glass	n_D for D	$n_F - n_C$	$v=\frac{n_D-1}{n_F-n_C}$	$n_D - n_A$	$n_F - n_D$	$n_{G'} - n_F$	Specific Weight.
O 225 Light phosphate crown	1.5159	.00737	70.0	.00485	.00515	.00407	2.58
O 802 Boro-silicate crown	1.4967	0765	64.9	0504	0534	0423	2.38
UV 3199 Ultra-violet crown	1.5035	0781	64.4	0514	0546	0432	2.41
O 227 Barium-silicate crown	1.5399	0909	59.4	0582	0639	0514	2.73
O 114 Soft-silicate crown	1.5151	0910	56.6	0577	0642	0521	2.55
O 608 High-dispersion crown	1.5149	0943	54.6	0595	0666	0543	2.60
UV 3248 Ultra-violet flint	1.5332	0964	55.4	0611	0680	0553	2.75
O 381 High-dispersion crown	1.5262	1026	51.3	0644	0727	0596	2.70
O 602 Baryt light flint	1.5676	1072	53.0	0675	0759	0618	3.12
S 389 Borate flint	1.5686	1102	51.6	0712	0775	0629	2.83
O 726 Extra light flint	1.5398	1142	47.3	0711	0810	0669	2.87
O 154 Ordinary light flint	1.5710	1327	43.0	0819	0943	0791	3.16
O 184 " " "	1.5900	1438	41.1	0882	1022	0861	3.28
O 748 Baryt flint	1.6235	1599	39.1	0965	1142	0965	3.67
O 102 Heavy flint	1.6489	1919	33.8	1152	1372	1180	3.87
O 41 " "	1.7174	2434	29.5	1439	1749	1521	4.49
O 165 " "	1.7541	2743	27.5	1607	1974	1730	4.78
S 386 Heavy flint	1.9170	4289	21.4	2451	3109	2808	6.01
S 57 Heaviest flint	1.9626	4882	19.7	2767	3547	3252	6.33

TABLE 393.—Change of Indices of Refraction for 1° C in Units of the Fifth Decimal Place.

No. and Designation.	Mean Temp.	C	D	F	G'	$-\frac{\Delta n}{n}100$
S 57 Heavy silicate flint	58.8°	1.204	1.447	2.090	2.810	0.0166
O 154 Light silicate flint	58.4	0.225	0.261	0.334	0.407	0.0078
O 327 Baryt flint light	58.3	−0.008	0.014	0.080	0.137	0.0079
O 225 Light phosphate crown	58.1	−0.202	−0.190	−0.168	−0.142	0.0049

Pulfrich, Wied. Ann. 45, p. 609, 1892.

TABLE 394.—Index of Refraction of Rock Salt in Air

$\lambda(\mu)$.	n.	Observer.	$\lambda(\mu)$.	n.	Observer.	$\lambda(\mu)$.	n.	Observer.
0.185409	1.89348	M	0.88396	1.534011	L	5.8932	1.516014	P
.204470	1.70964	"	.972298	1.532532	"	"	1.515553	L
.291368	1.61325	"	.98220	1.532435	P	6.4825	1.513628	P
.358702	1.57932	"	1.036758	1.531762	L	"	1.513467	L
.441587	1.55962	"	1.1786	1.530372	P	7.0718	1.511062	P
.486149	1.55338	"	"	1.530374	L	7.6611	1.508318	"
"	1.553406	L	1.555137	1.528211	"	7.9558	1.506804	"
"	1.553399	P	1.7680	1.527440	P	8.8398	1.502035	"
.58902	1.544340	L	"	1.527441	L	10.0184	1.494722	"
.58932	1.544313	P	2.073516	1.526554	"	11.7864	1.481816	"
656304	1.540672	P	2.35728	1.525863	P	12.9650	1.471720	"
"	1.540702	L	"	1.525849	L	14.1436	1.460547	"
.706548	1.538633	P	2.9466	1.524534	P	14.7330	1.454404	"
.766529	1.536712	P	3.5359	1.523173	"	15.3223	1.447494	"
.76824	1.53666	M	4.1252	1.521648	P	15.9116	1.441032	"
.78576	1.536138	P	"	1.521625	L	20.57	1.3735	RN
.88396	1.534011	P	5.0092	1.518978	P	22.3	1.340	"

$$n^2=a^2+\frac{M_1}{\lambda^2-\lambda_1^2}+\frac{M_2}{\lambda^2-\lambda_2^2}-k\lambda^2-h\lambda^4 \text{ or } =b^2+\frac{M_1}{\lambda^2-\lambda_1^2}+\frac{M_2}{\lambda^2-\lambda_2^2}-\frac{M_3}{\lambda_3^2-\lambda^2}$$

where $a^2=2.330165$ $\lambda_2^2=0.02547414$ $b^2=5.680137$
$M_1=0.01278685$ $k=0.0009285837$ $M_3=12059.95$
$\lambda_1^2=0.0148500$ $h=0.000000286086$ $\lambda_3^2=3600.$ (P)
$M_2=0.005343924$

TABLE 395.—Change of Index of Refraction for 1° C in Units of the 5th Decimal Place

0.202μ	+3.134	Mi	0.441μ	−3.425	Mi	C line	−3.749	Pl	0.760μ	−3.73	L
.210	+1.570	"	.508	−3.517	"	D "	−3.739	"	1.368	−3.88	L
.224	−0.187	"	.643	−3.636	"	F "	−3.648	"	1.88	−3.85	L
.298	−2.727	"				G′ "	−3.585	"	4.3	−3.82	L

L Annals of the Astrophysical Observatory of the Smithsonian Institution, Vol. I, 1900.
M Martens, Ann. d. Phys. 6, 1901, 8, 1902.
Mi Micheli, Ann. d. Phys. 7, 1902.
P Paschen, Wied. Ann. 26, 1908.
Pl Pulfrich, Wied. Ann. 45, 1892.
RN Rubens and Nichols, Wied. Ann. 60, 1897.

TABLE 396.—Index of Refraction of Sylvite (Potassium Chloride) in Air

$\lambda(\mu)$.	n.	Observer.	$\lambda(\mu)$.	n.	Observer.	$\lambda(\mu)$.	n.	Observer.
0.185409	1.82710	M	1.1786	1.478311	P	8.2505	1.462726	P
.200090	1.71870	"	"	1.47824	W	"	1.46276	W
.21946	1.64745	"	1.7680	1.475890	P	8.8398	1.460858	P
.257317	1.58125	"	"	1.47589	W	"	1.46092	W
.281640	1.55836	"	2.35728	1.474751	P	10.0184	1.45672	P
.308227	1.54136	"	2.9466	1.473834	"	"	1.45673	W
.358702	1.52115	"	"	1.47394	W	11.786	1.44919	P
.394415	1.51219	"	3.5359	1.473049	P	"	1.44941	W
.467832	1.50044	"	"	1.47304	W	12.965	1.44346	P
.508606	1.49620	"	4.7146	1.471122	P	"	1.44385	W
.58933	1.49044	P	"	1.47129	W	14.144	1.43722	P
.67082	1.48669	M	5.3039	1.470013	P	15.912	1.42617	"
.78576	1.483282	P	"	1.47001	W	17.680	1.41403	"
.88398	1.481422	P	5.8932	1.468804	P	20.60	1.3882	RN
.98220	1.480084	"	"	1.46880	W	22.5	1.369	"

$$n^2=a^2+\frac{M_1}{\lambda^2-\lambda_1^2}+\frac{M_2}{\lambda^2-\lambda_2^2}-k\lambda^2-h\lambda^4 \text{ or } =b^2+\frac{M_1}{\lambda^2-\lambda_1^2}+\frac{M_2}{\lambda^2-\lambda_2^2}+\frac{M_3}{\lambda_3^2-\lambda^2}$$

$a^2=2.174967$ $\lambda_2^2=0.0255550$ $b^2=3.866619$
$M_1=0.008344206$ $k=0.000513495$ $M_3=5569.715$
$\lambda_1^2=0.0119082$ $h=0.0000000167587$ $\lambda_3^2=3292.47$ (P)
$M_2=0.00698382$

W Weller, see Paschen's article. Other references as under Table 395, above.

INDEX OF REFRACTION

TABLE 397.—Index of Refraction of Fluorite in Air

λ (μ)	n	Observer	λ (μ)	n	Observer	λ (μ)	n	Observer
0.1856	1.50940	S	1.4733	1.42641	P	4.1252	1.40855	P
.19881	1.49629	"	1.5715	1.42596	"	4.4199	1.40559	"
.21441	1.48462	"	1.6206	1.42582	"	4.7146	1.40238	"
.22645	1.47762	"	1.7680	1.42507	"	5.0092	1.39898	"
.25713	1.46476	"	1.9153	1.42437	"	5.3036	1.39529	"
.32525	1.44987	"	1.9644	1.42413	"	5.5985	1.39142	"
.34555	1.44697	"	2.0626	1.42359	"	5.8932	1.38719	"
.39681	1.44214	"	2.1608	1.42308	"	6.4825	1.37819	"
.48607	1.43713	P	2.2100	1.42288	"	7.0718	1.36805	"
.58930	1.43393	P	2.3573	1.42199	"	7.6612	1.35680	"
.65618	1.43257	S	2.5537	1.42088	"	8.2505	1.34444	"
.68671	1.43200	"	2.6519	1.42016	"	8.8398	1.33079	"
.71836	1.43157	"	2.7502	1.41971	"	9.4291	1.31612	"
.76040	1.43101	"	2.9466	1.41826	"	51.2	3.47	RA
.8840	1.42982	P	3.1430	1.41707	"	61.1	2.66	"
1.1786	1.42787	"	3.2413	1.41612	"	∞	2.63	S
1.3756	1.42690	"	3.5359	1.41379	"			
1.4733	1.42641	"	3.8306	1.41120	"			

References under Table 331.

$$n^2 = a^2 + \frac{M_1}{\lambda^2 - \lambda_1^2} - e\lambda^2 - f\lambda^4 \text{ or } = b^2 + \frac{M_2}{\lambda^2 - \lambda_v^2} + \frac{M_3}{\lambda^2 - \lambda_r^2}$$

where $a^2 = 2.03882$, $f = 0.000002916$, $M_3 = 5114.65$, $M_1 = 0.0062183$, $b^2 = 6.09651$, $\lambda_r^2 = 1260.56$, $\lambda_1^2 = 0.007706$, $M_2 = 0.0061386$, $\lambda_v = 0.0940\mu$, $e = 0.0031999$, $\lambda_v^2 = 0.00884$, $\lambda_r = 35.5\mu$ (P)

TABLE 398.—Change of Index of Refraction for 1° C in Units of the 5th Decimal Place

C line, —1.220; D, —1.206; F, —1.170; G, —1.142. (Pl)

TABLE 399.—Index of Refraction of Iceland Spar ($CaCO_3$) in Air

λ (μ)	n_o	n_e	Observer	λ (μ)	n_o	n_e	Observer	λ (μ)	n_o	n_e	Observer
0.198	–	1.5780	M	0.508	1.6653	1.4896	M	0.991	1.6438	1.4802	C
.200	1.9028	1.5765	"	.533	1.6628	1.4884	"	1.229	1.6393	1.4787	"
.208	1.8673	1.5664	"	.589	1.6584	1.4864	"	1.307	1.6379	1.4783	"
.226	1.8130	1.5492	–	.643	1.6550	1.4849	"	1.497	1.6346	1.4774	"
.298	1.7230	1.5151	C	.656	1.6544	1.4846	"	1.682	1.6313	-	"
.340	1.7008	1.5056	M	.670	1.6537	1.4843	"	1.749	–	1.4764	"
.361	1.6932	1.5022	C	.760	1.6500	1.4826	–	1.849	1.6280	–	"
.410	1.6802	1.4964	–	.768	1.6497	1.4826	M	1.908	–	1.4757	"
.434	1.6755	1.4943	M	.801	1.6487	1.4822	C	2.172	1.6210	–	"
.486	1.6678	1.4907	"	.905	1.6458	1.4810	"	2.324	–	1.4739	"

C Carvallo, J. de Phys. (3), 9, 1900.
M Martens, Ann. der Phys. (4) 6, 1901, 8, 1902.
P Paschen, Wied Ann. 56, 1895.
Pl Pulfrich, Wied. Ann 45, 1892.
RA Rubens-Aschkinass, Wied. Ann. 67, 1899.
S Starke, Wied. Ann. 60, 1897.

TABLE 400.—Index of Refraction of Nitroso-dimethyl-aniline (Wood)

λ	n	λ	n	λ	n	λ	n	λ	n
0.497	2.140	0.525	1.945	0.584	1.815	0.636	1.647	0.713	1.718
.500	2.114	.536	1.909	.602	1.796	.647	1.758	.730	1.713
.506	2.074	.546	1.879	.611	1.783	.659	1.750	.749	1.709
.508	2.025	.557	1.857	.620	1.778	.669	1.743	.763	1.697
.516	1.985	.569	1.834	.627	1.769	.696	1.723		

Nitroso-dimethyl-aniline has enormous dispersion in yellow and green, metallic absorption in violet. See Wood. Phil. Mag 1903.

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TABLE 401.—Index of Refraction of Quartz (SiO_2), 18°C

Wave length	Index Ordinary Ray	Index Extra-ordinary Ray	Fused	Wave-length	Index Ordinary Ray	Index Extra-ordinary Ray	Fused
μ				μ			
0.185	1.67582	1.68999	1.5745	0.656	1.54189	1.55091	1.45640
.193	.65997	.67343	1.5603	.686	.54099	.54998	.....
.198	.65090	.66397	1.55202	.760	.53917	.54811	.....
.206	.64038	.65300	.....	1.160	.5329		.....
.214	.63041	.64264	1.53388	.969	.5216		.....
.219	.62494	.63698	1.52911	2.327	.5156		.....
.231	.61399	.62560	1.5194	.84	.5039		.....
.257	.59622	.60712	1.5037	3.18	.4944		.....
.274	.58752	.59811	1.49623	.63	.4799	Rubens	.....
.340	.56748	.57738	1.4788	.96	.4679		.....
.396	.55815	.56771	.....	4.20	.4569		.....
.410	.55650	.56600	.....	5.0	.417		.....
.486	.54968	.55896	.....	6.45	.274		.....
0.589	1.54424	1.55334	1.45845	7.0	1.167		.....

Except Rubens' values,—means from various authorities

TABLE 402.—Index of Refraction for Various Alums*

R	Density.	Temp. C.°	Index of refraction for the Fraunhofer lines. a	B	c	D	E	b	F	G
			Aluminium Alums. $R\mathrm{Al(SO_4)_2+12H_2O}$.†							
Na	1.667	17–28	1.43492	1.43563	1.43653	1.43884	1.44185	1.44231	1.44412	1.44804
$NH_3(CH_3)$	1.568	7–17	.45013	.45062	.45177	.45410	.45691	.45749	.45941	.46363
K	1.735	14–15	.45226	.45303	.45398	.45645	.45934	.45996	.46181	.46609
Rb	1.852	7–21	.45232	.45328	.45417	.45660	.45955	.45999	.46192	.46618
Cs	1.961	15–25	.45437	.45517	.45618	.45856	.46141	.46203	.46386	.46821
NH_4	1.631	15–20	.45509	.45599	.45693	.45939	.46234	.46288	.46481	.46923
Tl	2.329	10–23	.49226	.49317	.49443	.49748	.50128	.50209	.50463	.51076
			Chrome Alums. $R\mathrm{Cr(SO_4)_2+12H_2O}$.†							
Cs	2.043	6–12	1.47627	1.47732	1.47836	1.48100	1.48434	1.48491	1.48723	1.49280
K	1.817	6–17	.47642	.47738	.47865	.48137	.48459	.48513	.48753	.49309
Rb	1.946	12–17	.47660	.47756	.47868	.48151	.48486	.48522	.48775	.49323
NH_4	1.719	7–18	.47911	.48014	.48125	.48418	.48744	.48794	.49040	.49594
Tl	2.386	9–25	.51692	.51798	.51923	.52280	.52704	.52787	.53082	.53808
			Iron Alums. $R\mathrm{Fe(SO_4)_2+12H_2O}$.†							
K	1.806	7–11	1.47639	1.47706	1.47837	1.48169	1.48580	1.48670	1.48939	1.49605
Rb	1.916	7–20	.47700	.47770	.47894	.48234	.48654	.48712	.49003	.49700
Cs	2.061	20–24	.47825	.47921	.48042	.48378	.48797	.48867	.49136	.49838
NH_4	1.713	7–20	.47927	.48029	.48150	.48482	.48921	.48993	.49286	.49980
Tl	2.385	15–17	.51674	.51790	.51943	.52365	.52859	.52946	.53284	.54112

* According to the experiments of Soret (Arch. d. Sc. Phys. Nat. Genève, 1884, 1888, and Comptes Rendus, 1885).
† *R* stands for the different bases given in the first column.
For other alums see reference on Landolt-Börnstein-Roth Tabellen.

TABLE 403

INDEX OF REFRACTION

Selected Monorefringent or Isotropic Minerals

The values are for the sodinm D line unless otherwise stated and are arranged in the order of increasing indices Selected by Dr. Edgar T. Wherry from a private compilation of Dr. E. S. Larsen of the U. S. Geological Survey.

Mineral.	Formula.	Index of refraction, $\lambda = 0.589\mu$.
Villiaumite	NaF	1.328
Cryolithionite	$3NaF.3LiF.2AlF_3$	1.339
Opal	$SiO_2.nH_2O$	1.406–1.440
Fluorite	CaF_2	1.434
Alum	$K_2O.Al_2O_3.4SO_3.24H_2O$	1.450
Sodalite	$3Na_2O.3Al_2O_3.6SiO_2.2NaCl$	1.483
Cristobalite	SiO_2	1.486
Analcite	$Na_2O.Al_2O_3.4SiO_2.2H_2O$	1.487
Sylvite	KCl	1.490
Noselite	$5Na_2O.3Al_2O_3.6SiO_2.2SO_3$	1.495
Hauynite	Like preceding + CaO	1.496
Lazurite	$4Na_2O.3Al_2O_3.6SiO_2.Na_2S_6$	1.500 ±
Leucite	$K_2O.Al_2O_3.4SiO_2$	1.509
Pollucite	$2Cs_2O.2Al_2O_3.9SiO_2.H_2O$	1.525
Halite	$NaCl$	1.544
Bauxite	$Al_2O_3.nH_2O$	1.570 ±
Pharmacosiderite	$3Fe_2O_3.2As_2O_5.3K_2O.5H_2O$	1.676
Spinel	$MgO.Al_2O_3$	1.723 ±
Berzeliite	$3(Ca, Mg, Mn)O.As_2O_5$	1.727
Periclasite	MgO	1.736
Grossularite	$3CaO.Al_2O_3.3SiO_2$	1.736
Helvite	$3(Mn, Fe)O.3BeO.3SiO_2.MnS$	1.739
Pyrope	$3MgO.Al_2O_3.3SiO_2$	1.745
Arsenolite	As_2O_3	1.755
Hessonite	$3CaO.(Al, Fe)_2O_3.3SiO_2$	1.763
Pleonaste	$(Mg, Fe)O.Al_2O_3$	1.770 ±
Almandite	$3FeO.Al_2O_3.3SiO_2$	1.778
Hercynite	$FeO.Al_2O_3$	1.800 ±
Gahnite	$ZnO.Al_2O_3$	1.800 ±
Spessartite	$3MnO.Al_2O_3.3SiO_2$	1.811
Lime	CaO	1.830
Uvarovite	$3CaO.Cr_2O_3.3SiO_2$	1.838
Andradite	$3CaO.Fe_2O_3.3SiO_2$	1.857
Microlite	$6CaO.3Ta_2O_5.CbOF_3$	1.925
Nantokite	$CuCl$	1.930
Pyrochlore	Contains CaO, Ce_2O_3, TiO_2, etc.	1.960–2.000
Schorlomite	$3CaO.(Fe, Ti)_2O_3.3(Si, Ti)O_2$	1.980
Percylite	$PbO.CuCl_2.H_2O$	2.050
Picotite	$(Mg, Fe)O.(Al, Cr)_2O_3$	2.050 ±
Eulytite	$2Bi_2O_3.3SiO_2$	2.050
Cerargyrite	$AgCl$	2.061
Mosesite	Contains Hg, NH_4, Cl, etc.	2.065
Chromite	$FeO.Cr_2O_3$	2.070
Senarmontite	Sb_2O_3	2.087
Embolite	$Ag(Br, Cl)$	2.150 ±
Manganosite	MnO	2.160
Bunsenite	NiO	2.18 (Li light)
Lewisite	$5CaO.2TiO_2.3Sb_2O_5$	2.200
Miersite	$CuI.4AgI$	2.200
Bromyrite	$AgBr$	2.253
Dysanalite	Contains CaO, FeO, TiO_2, etc.	2.330
Marshite	CuI	2.346
Franklinite	$(Zn, Fe, Mn)O.(Fe, Mn)_2O_3$	2.360 (Li light)
Sphalerite	$(Zn, Fe)S$	2.370–2.470
Perovskite	$CaO.TiO_2$	2.380
Diamond	C	2.419
Eglestonite	$HgO.2HgCl$	2.490 (Li light)
Hauerite	MnS_2	2.690 (Li light)
Alabandite	MnS	2.700 (Li light)
Cuprite	Cu_2O	2.849

TABLE 404

INDEX OF REFRACTION

Miscellaneous Monorefringent or Isotropic Solids

Substance.	Spectrum line.	Index of refraction.	Authority.
Albite glass	D	1.4890	Larsen, 1909
Amber	D	1.546	Mühlheim
Ammonium chloride	D	1.6422	Grailich
Anorthite glass	D	1.5755	Larsen, 1909
Asphalt	D	1.635	E. L. Nichols
"	0.670μ	1.621	" " "
Bell metal	D	1.0052	Beer
Boric Acid, melted	C	1.4623	Bedson and Williams
" " "	D	1.4637	" " "
" " "	F	1.4694	" " "
Borax, melted	C	1.4624	" " "
" "	D	1.4630	" " "
" "	F	1.4702	" " "
Camphor	D	1.532	Kohlrausch
"	D	1.5462	Mühlheim
Canada balsam	D	1.530	Mean
Ebonite	red	1.66	Ayrton, Perry
Fuchsin	A	2.03	Mean
"	B	2.19	"
"	C	2.33	"
"	G	1.97	"
"	H	1.32	"
Gelatin, Nelson no. 1	D	1.530	Jones, 1911
" various	D	1.516–1.534	" "
Gum Arabic	red	1.480	Jamin
" "	red	1.514	Wollaston
Obsidian	D	1.482–1.496	Various
Phosphorus	D	2.1442	Gladstone, Dale
Pitch	red	1.531	Wollaston
Potassium bromide	D	1.5593	Topsöe, Christiansen
" chlorstannate	D	1.6574	" "
" iodide	D	1.6666	" "
Resins: Aloes	red	1.619	Jamin
Canada balsam	red	1.528	Wollaston
Colophony	red	1.548	Jamin
Copal	red	1.528	"
Mastic	red	1.535	Wollaston
Peru balsam	D	1.593	Baden Powell
Selenium	A	2.61	Wood
"	B	2.68	"
"	C	2.73	"
"	D	2.93	"
Sodium chlorate	D	1.5150	Dussaud
Strontium nitrate	D	1.5667	Fock

TABLE 405

INDEX OF REFRACTION

Selected Uniaxial Minerals

The values are arranged in the order of increasing indices for the ordinary ray and are for the sodium D line unless otherwise indicated. Selected by Dr. Edgar T. Wherry from a private compilation of Dr. Esper S. Larsen of the U. S. Geological Survey.

Mineral.	Formula.	Index of refraction. Ordinary ray.	Index of refraction. Extraordinary ray.
(a) UNIAXIAL POSITIVE MINERALS.			
Ice	H_2O	1.309	1.313
Sellaite	MgF_2	1.378	1.390
Chrysocolla	$CuO.SiO_2.2H_2O$	1.460 ±	1.570 ±
Laubanite	$2CaO.Al_2O_3.5SiO_2.6H_2O$	1.475	1.486
Chabazite	$(Ca, Na_2)O.Al_2O_3.4SiO_2.6H_2O$	1.480 ±	1.482 ±
Douglasite	$2KCl.FeCl_2.2H_2O$	1.488	1.500
Hydronephelite	$2Na_2O.3Al_2O_3.6SiO_2.7H_2O$	1.490	1.502
Apophyllite	$K_2O.8CaO.16SiO_2.16H_2O$	1.535 ±	1.537 ±
Quartz	SiO_2	1.544	1.553
Coquimbite	$Fe_2O_3.3SO_3.9H_2O$	1.550	1.556
Brucite	$MgO.H_2O$	1.559	1.580
Alunite	$K_2O.3Al_2O_3.4SO_3.6H_2O$	1.572	1.592
Penninite	$5(Mg, Fe)O.Al_2O_3.3SiO_2.4H_2O$	1.576	1.579
Cacoxenite	$2Fe_2O_3.P_2O_5.12H_2O$	1.582	1.645
Eudialite	$6Na_2O.6(Ca, Fe)O.20(Si, Zr)O_2.NaCl$	1.606	1.611
Dioptasite	$CuO.SiO_2.H_2O$	1.654	1.707
Phenacite	$2BeO.SiO_2$	1.654	1.670
Parisite	$2CeOF.CaO.3CO_2$	1.676	1.757
Willemite	$2ZnO.SiO_2$	1.694	1.723
Vesuvianite	$2(Ca, Mn, Fe)O.(Al, Fe)(OH, F)O.2SiO_2$	1.716 ±	1.718 ±
Xenotime	$Y_2O_3.P_2O_5$	1.721	1.816
Connellite	$20CuO.SO_3.2CuCl_2.20H_2O$	1.724	1.746
Benitoite	$BaO.TiO_2.3SiO_2$	1.757	1.804
Ganomalite	$6PbO.4(Ca, Mn)O.6SiO_2.H_2O$	1.910	1.945
Scheelite	$CaO.WO_3$	1.918	1.934
Zircon	$ZrO_2.SiO_2$	1.923 ±	1.968 ±
Powellite	$CaO.MoO_3$	1.967	1.978
Calomel	$HgCl$	1.973	2.650
Cassiterite	SnO_2	1.997	2.093
Zincite	ZnO	2.008	2.029
Phosgenite	$PbO.PbCl_2.CO_2$	2.114	2.140
Penfieldite	$PbO.2PbCl_2$	2.130	2.210
Iodyrite	AgI	2.210	2.220
Tapiolite	$FeO.(Ta, Cb)_2O_5$	2.270	2.420 (Li light)
Wurtzite	ZnS	2.356	2.378
Derbylite	$6FeO.Sb_2O_3.5TiO_2$	2.450	2.510 (Li light)
Greenockite	CdS	2.506	2.529
Rutile	TiO_2	2.616	2.903
Moissanite	CSi	2.654	2.697
Cinnabarite	HgS	2.854	3.201
(b) UNIAXIAL NEGATIVE MINERALS.			
Chiolite	$2NaF.AlF_3$	1.349	1.342
Hanksite	$11Na_2O.9SO_3.2CO_2.KCl$	1.481	1.461
Thaumasite	$3CaO.CO_2.SiO_2.SO_3.15H_2O$	1.507	1.468
Hydrotalcite	$6MgO.Al_2O_3.CO_2.15H_2O$	1.512	1.498
Cancrinite	$4Na_2O.CaO.4Al_2O_3.2CO_2.9SiO_2.3H_2O$	1.524	1.496
Milarite	$K_2O.4CaO.2Al_2O_3.24SiO_2.H_2O$	1.532	1.529
Kaliophilite	$K_2O.Al_2O_3.2SiO_2$	1.537	1.533
Mellite	$Al_2O_3.C_{12}O_9.18H_2O$	1.539	1.511
Marialite	"Ma" = $3Na_2O.3Al_2O_3.18SiO_2.2NaCl$	1.539	1.537
Nephelite	$Na_2O.Al_2O_3.2SiO_2$	1.542	1.538

INDEX OF REFRACTION

TABLE 405 (*Continued*). — Selected Uniaxial Minerals

Mineral.	Formula.	Index of refraction. Ordinary ray.	Index of refraction. Extraordinary ray.
(*b*) UNIAXIAL NEGATIVE MINERALS (*continued*).			
Wernerite	Me_1Ma_1 ±	1.578	1.551
Beryl	$3BeO.Al_2O_3.6SiO_2$	1.581 ±	1.575 ±
Torbernite	$CuO.2UO_3.P_2O_5.8H_2O$	1.592	1.582
Meionite	"Me" = $4CaO.3Al_2O_3.6SiO_2$	1.597	1.560
Melilite	Contains Na_2O, CaO, Al_2O_3, SiO_2, etc.	1.634	1.629
Apatite	$9CaO.3P_2O_5.Ca(F, Cl)_2$	1.634	1.631
Calcite	$CaO.CO_2$	1.658	1.486
Gehlenite	$2CaO.Al_2O_3.SiO_2$	1.669	1.658
Tourmaline	Contains Na_2O, FeO, Al_2O_3, B_2O_3, SiO_2, etc.	1.669 ±	1.638 ±
Dolomite	$CaO.MgO.2CO_2$	1.682	1.503
Magnesite	$MgO.CO_2$	1.700	1.509
Pyrochroite	$MnO.H_2O$	1.723	1.681
Corundum	Al_2O_3	1.768	1.760
Smithsonite	$ZnO.CO_2$	1.818	1.618
Rhodochrosite	$MnO.CO_2$	1.818	1.595
Jarosite	$K_2O.3Fe_2O_3.4SO_3.6H_2O$	1.820	1.715
Siderite	$FeO.CO_2$	1.875	1.635
Pyromorphite	$9PbO.3P_2O_5.PbCl_2$	2.050	2.042
Barysilite	$3PbO.2SiO_2$	2.070	2.050
Mimetite	$9PbO.3As_2O_5.PbCl_2$	2.135	2.118
Matlockite	$PbO.PbCl_2$	2.150	2.040
Stolzite	$PbO.WO_3$	2.269	2.182
Geikielite	$(Mg, Fe)O.TiO_2$	2.310	1.950
Vanadinite	$9PbO.3V_2O_5.PbCl_2$	2.354	2.299
Wulfenite	$PbO.MoO_3$	2.402	2.304 (Li light)
Octahedrite	TiO_2	2.554	2.493
Massicotite	PbO	2.665	2.535 (Li light)
Proustite	$3Ag_2S.As_2S_3$	2.979	2.711 " "
Pyrargyrite	$3Ag_2S.Sb_2S_3$	3.084	2.881 " "
Hematite	Fe_2O_3	3.220	2.940 " "

TABLE 406. — Miscellaneous Uniaxial Crystals

Crystal.	Spectrum line.	Index of refraction. Ordinary ray.	Index of refraction. Extraordinary ray.	Authority.
Ammonium arseniate $NH_4H_2AsO_4$	D	1.5766	1.5217	T. and C.*
Benzil $(C_6H_5CO)_2$	D	1.6588	1.6784	Mean
Corundum, Al_2O_3, sapphire, ruby	D	1.769	1.760	Osann
Ice at −8° C.	D	1.308	1.313	Meyer
" " " "	Li	1.297	1.304	"
Ivory	D	1.539	1.541	Kohlrausch
Potassium arseniate KH_2AsO_4	F	1.5762	1.5252	T. and C.
" " "	D	1.5674	1.5179	" " "
" " "	C	1.5632	1.5146	" " "
Sodium arseniate $Na_3AsO_4.12H_2O$	D	1.457	1.466	Mean
" nitrate $NaNO_3$	D	1.586	1.336	"
" phosphate $Na_3PO_4.12H_2O$	D	1.447	1.453	"
Nickel sulphate $NiSO_4.6H_2O$	F	1.5173	1.4930	T. and C.
" " "	D	1.5109	1.4873	" " "
" " "	C	1.5078	1.4844	" " "
Strychnine sulphate	D	1.614	1.599	Martin

* Topsöe and Christiansen.

TABLE 407

INDEX OF REFRACTION

Selected Biaxial Minerals

The values are arranged in the order of increasing β index of refraction and are for the sodium D line except where noted. Selected by Dr. Edgar T. Wherry from private compilation of Dr. Esper S. Larsen of the U. S. Geological Survey.

Mineral.	Formula.	Index of refraction.		
		n_α	n_β	n_γ
(a) BIAXIAL POSITIVE MINERALS.				
Stercorite	$Na_2O.(NH_4)_2O.P_2O_5.9H_2O$	1.439	1.441	1.469
Aluminite	$Al_2O_3.SO_3.9H_2O$	1.459	1.464	1.470
Tridymite	SiO_2	1.469	1.470	1.473
Thenardite	$Na_2O.SO_3$	1.464	1.474	1.485
Carnallite	$KCl.MgCl_2.6H_2O$	1.466	1.475	1.494
Alunogenite	$Al_2O_3.3SO_3.16H_2O$	1.474	1.476	1.483
Melanterite	$FeO.SO_3.7H_2O$	1.471	1.478	1.486
Natrolite	$Na_2O.Al_2O_3.3SiO_2.2H_2O$	1.480	1.482	1.493
Arcanite	$K_2O.SO_3$	1.494	1.495	1.497
Struvite	$(NH_4)_2O.2MgO.P_2O_5.12H_2O$	1.495	1.496	1.504
Heulandite	$CaO.Al_2O_3.6SiO_2.3H_2O$	1.498	1.499	1.505
Thomsonite	$(Na_2, Ca)O.Al_2O_3.2SiO_2.3H_2O$	1.497	1.503	1.525
Harmotomite	$(K_2, Ba)O.Al_2O_3.5SiO_2.5H_2O$	1.503	1.505	1.508
Petalite	$Li_2O.Al_2O_3.8SiO_2$	1.504	1.510	1.516
Monetite	$2CaO.P_2O_5.H_2O$	1.515	1.518	1.525
Newberyite	$2MgO.P_2O_5.7H_2O$	1.514	1.519	1.533
Gypsum	$CaO.SO_3.2H_2O$	1.520	1.523	1.530
Mascagnite	$(NH_4)_2O.SO_3$	1.521	1.523	1.533
Albite	"Ab" = $Na_2O.Al_2O_3.6SiO_2$	1.525	1.529	1.536
Hydromagnesite	$4MgO.3CO_2.4H_2O$	1.527	1.530	1.540
Wavellite	$3Al_2O_3.2P_2O_5.12(H_2O, 2HF)$	1.525	1.534	1.552
Kieserite	$MgO.SO_3.H_2O$	1.523	1.535	1.586
Copiapite	$2Fe_2O_3.5SO_3.18H_2O$	1.530	1.543	1.595
Whewellite	$CaO.C_2O_3.H_2O$	1.491	1.555	1.650
Variscite	$Al_2O_3.P_2O_5.4H_2O$	1.551	1.558	1.582
Labradorite	Ab_2An_3	1.559	1.563	1.568
Gibbsite	$Al_2O_3.3H_2O$	1.566	1.566	1.587
Wagnerite	$3MgO.P_2O_5.MgF_2$	1.569	1.570	1.582
Anhydrite	$CaO.SO_3$	1.571	1.576	1.614
Colemanite	$2CaO.3B_2O_3.5H_2O$	1.586	1.592	1.614
Fremontite	$Na_2O.Al_2O_3.P_2O_5.(H_2O, 2HF)$	1.594	1.603	1.615
Vivianite	$3FeO.P_2O_5.8H_2O$	1.579	1.603	1.633
Pectolite	$Na_2O.4CaO.6SiO_2.H_2O$	1.595	1.606	1.634
Calamine	$2ZnO.SiO_2.H_2O$	1.614	1.617	1.636
Chondrodite	$4MgO.2SiO_2.Mg(F, OH)_2$	1.609	1.619	1.639
Turquois	$CuO.3Al_2O_3.2P_2O_5.9H_2O$	1.610	1.620	1.650
Topaz	$2AlOF.SiO_2$	1.619	1.620	1.627
Celestite	$SrO.SO_3$	1.622	1.624	1.631
Prehnite	$2CaO.Al_2O_3.3SiO_2.H_2O$	1.616	1.626	1.649
Barite	$BaO.SO_3$	1.636	1.637	1.648
Anthophyllite	$MgO.SiO_2$	1.633	1.642	1.657
Sillimanite	$Al_2O_3.SiO_2$	1.638	1.642	1.653
Forsterite	$2MgO.SiO_2$	1.635	1.651	1.670
Enstatite	$MgO.SiO_2$	1.650	1.653	1.658
Euclasite	$2BeO.Al_2O_3.2SiO_2.H_2O$	1.652	1.655	1.671
Triplite	$3MnO.P_2O_5.MnF_2$	1.650	1.660	1.672
Spodumenite	$Li_2O.Al_2O_3.4SiO_2$	1.660	1.666	1.676
Diopside	$CaO.MgO.2SiO_2$	1.664	1.671	1.694
Olivine	$2(Mg, Fe)O.SiO_2$	1.662	1.680	1.699
Triphylite	$Li_2O.2(Fe, Mn)O.P_2O_5$	1.688	1.688	1.692

TABLE 407 (*continued*)

INDEX OF REFRACTION

Selected Biaxial Minerals

Mineral.	Formula.	Index of refraction. n_α	n_β	n_γ
(*a*) BIAXIAL POSITIVE MINERALS (*continued*).				
Zoisite	$4CaO.3Al_2O_3.6SiO_2.H_2O$	1.700	1.702	1.706
Strengite	$Fe_2O_3.P_2O_5.4H_2O$	1.710	1.710	1.745
Diasporite	$Al_2O_3.H_2O$	1.702	1.722	1.750
Staurolite	$2FeO.5Al_2O_3.4SiO_2.H_2O$	1.736	1.741	1.746
Chrysoberyl	$BeO.Al_2O_3$	1.747	1.748	1.757
Azurite	$3CuO.2CO_2.H_2O$	1.730	1.758	1.838
Scorodite	$Fe_2O_3.As_2O_5.4H_2O$	1.765	1.774	1.797
Olivenite	$4CuO.As_2O_5.H_2O$	1.772	1.810	1.863
Anglesite	$PbO.SO_3$	1.877	1.882	1.894
Titanite	$CaO.TiO_2.SiO_2$	1.900	1.907	2.034
Claudetite	As_2O_3	1.871	1.920	2.010
Sulfur	S	1.950	2.043	2.240
Cotunnite	$PbCl_2$	2.200	2.217	2.260
Huebnerite	$MnO.WO_3$	2.170	2.220	2.320
Manganite	$Mn_2O_3.H_2O$	2.240	2.240	2.530 (Li)
Raspite	$PbO.WO_3$	2.270	2.270	2.300
Mendipite	$2PbO.PbCl_2$	2.240	2.270	2.310
Tantalite	$(Fe, Mn)O.Ta_2O_5$	2.260	2.320	2.430 (Li)
Wolframite	$(Fe, Mn)O.WO_3$	2.310	2.360	2.460 (Li)
Crocoite	$PbO.CrO_3$	2.310	2.370	2.660 (Li)
Pseudobrookite	$2Fe_2O_3.3TiO_2$	2.380	2.390	2.420 (Li)
Stibiotantalite	$Sb_2O_3.Ta_2O_5$	2.374	2.404	2.457
Montroydite	HgO	2.370	2.500	2.650 (Li)
Brookite	TiO_2	2.583	2.586	2.741
Lithargite	PbO	2.510	2.610	2.710
(*b*) BIAXIAL NEGATIVE MINERALS.				
Mirabilite	$Na_2O.SO_3.10H_2O$	1.394	1.396	1.398
Thomsenolite	$NaF.CaF_2.AlF_3.H_2O$	1.407	1.414	1.415
Natron	$Na_2O.CO_2.10H_2O$	1.405	1.425	1.440
Kalinite	$K_2O.Al_2O_3.4SO_3.24H_2O$	1.430	1.452	1.458
Epsomite	$MgO.SO_3.7H_2O$	1.433	1.455	1.461
Sassolite	$B_2O_3.H_2O$	1.340	1.456	1.459
Borax	$Na_2O.2B_2O_3.10H_2O$	1.447	1.470	1.472
Goslarite	$ZnO.SO_3.7H_2O$	1.457	1.480	1.484
Pickeringite	$MgO.Al_2O_3.4SO_3.22H_2O$	1.476	1.480	1.483
Bloedite	$Na_2O.MgO.2SO_3.4H_2O$	1.486	1.488	1.489
Trona	$3Na_2O.4CO_2.5H_2O$	1.410	1.492	1.542
Thermonatrite	$Na_2O.CO_2.H_2O$	1.420	1.495	1.518
Stilbite	$(Ca, Na_2)O.Al_2O_3.6SiO_2.5H_2O$	1.494	1.498	1.500
Niter	$K_2O.N_2O_5$	1.334	1.505	1.506
Kainite	$MgO.SO_3.KCl.3H_2O$	1.494	1.505	1.516
Gaylussite	$Na_2O.CaO.2CO_2.5H_2O$	1.444	1.516	1.523
Scolecite	$CaO.Al_2O_3.3SiO_2.3H_2O$	1.512	1.519	1.519
Laumontite	$CaO.Al_2O_3.4SiO_2.4H_2O$	1.513	1.524	1.525
Orthoclase	$K_2O.Al_2O_3.6SiO_2$	1.518	1.524	1.526
Microcline	Same as preceding	1.522	1.526	1.530
Anorthoclase	$(Na, K)_2O.Al_2O_3.6SiO_2$	1.523	1.529	1.531
Glauberite	$Na_2O.CaO.2SO_3$	1.515	1.532	1.536
Cordierite	$4(Mg, Fe)O.4Al_2O_3.10SiO_2.H_2O$	1.534	1.538	1.540
Chalcanthite	$CuO.SO_3.5H_2O$	1.516	1.539	1.546
Oligoclase	Ab_4An	1.539	1.543	1.547

TABLE 407 (*Concluded*)

INDEX OF REFRACTION

Selected Biaxial Minerals

Mineral.	Formula.	Index of refraction.		
		n_α	n_β	n_γ
(*b*) BIAXIAL NEGATIVE CRYSTALS (*continued*).				
Beryllonite	$Na_2O.2BeO.P_2O_5$	1.552	1.558	1.561
Kaolinite	$Al_2O_3.2SiO_2.2H_2O$	1.561	1.563	1.565
Biotite	$K_2O.4(Mg, Fe)O.2Al_2O_3.6SiO_2.H_2O$	1.541	1.574	1.574
Autunite	$CaO.2UO_3.P_2O_5.8H_2O$	1.553	1.575	1.577
Anorthite	"An" = $CaO.Al_2O_3.2SiO_2$	1.576	1.584	1.588
Lanthanite	$La_2O_3.3CO_2.9H_2O$	1.520	1.587	1.613
Pyrophyllite	$Al_2O_3.4SiO_2.H_2O$	1.552	1.588	1.600
Talc	$3MgO.4SiO_2.H_2O$	1.539	1.589	1.589
Hopeite	$3ZnO.P_2O_5.4H_2O$	1.572	1.590	1.590
Muscovite	$K_2O.3Al_2O_3.6SiO_2.2H_2O$	1.561	1.590	1.594
Amblygonite	$Al_2O_3.P_2O_5.2LiF$	1.579	1.593	1.597
Lepidolite	$Al_2O_3.3SiO_2.2(K, Li)F$	1.560	1.598	1.605
Phlogopite	$K_2O.6MgO.Al_2O_3.6SiO_2.2H_2O$	1.562	1.606	1.606
Tremolite	$CaO.3MgO.4SiO_2$	1.609	1.623	1.635
Actinolite	$CaO.3(Mg, Fe)O.4SiO_2$	1.611	1.627	1.636
Wollastonite	$CaO.SiO_2$	1.616	1.629	1.631
Lazulite	$(Fe, Mg)O.Al_2O_3.P_2O_5.H_2O$	1.603	1.632	1.639
Danburite	$CaO.B_2O_3.2SiO_2$	1.632	1.634	1.636
Glaucophanite	$Na_2O.2FeO.Al_2O_3.6SiO_2$	1.621	1.638	1.638
Andalusite	$Al_2O_3.SiO_2$	1.632	1.638	1.643
Hornblende	Contains Na_2O, MgO, FeO, SiO_2, etc.	1.629	1.642	1.653
Datolite	$2CaO.2SiO_2.B_2O_3.H_2O$	1.625	1.653	1.669
Erythrite	$3CoO.As_2O_5.8H_2O$	1.626	1.661	1.699
Monticellite	$CaO.MgO.SiO_2$	1.651	1.662	1.668
Strontianite	$SrO.CO_2$	1.520	1.667	1.667
Witherite	$BaO.CO_2$	1.529	1.676	1.677
Aragonite	$CaO.CO_2$	1.531	1.682	1.686
Axinite	$6(Ca, Mn)O.2Al_2O_3.B_2O_3.8SiO_2.H_2O$	1.678	1.685	1.688
Dumortierite	$8Al_2O_3.B_2O_3.6SiO_2.H_2O$	1.678	1.686	1.689
Cyanite	$Al_2O_3.SiO_2$	1.712	1.720	1.728
Epidote	$4CaO.3(Al, Fe)_2O_3.6SiO_2.H_2O$	1.729	1.754	1.768
Atacamite	$3CuO.CuCl_2.3H_2O$	1.831	1.861	1.880
Fayalite	$2FeO.SiO_2$	1.824	1.864	1.874
Caledonite	$2(Pb, Cu)O.SO_3.H_2O$	1.818	1.866	1.909
Malachite	$2CuO.CO_2.H_2O$	1.655	1.875	1.909
Lanarkite	$2PbO.SO_3$	1.930	1.990	2.020
Leadhillite	$4PbO.SO_3.2CO_2.H_2O$	1.870	2.000	2.010
Cerussite	$PbO.CO_2$	1.804	2.076	2.078
Laurionite	$PbCl_2.PbO.H_2O$	2.077	2.116	2.158
Matlockite	$PbO.PbCl_2$	2.040	2.150	2.150
Baddeleyite	ZrO_2	2.130	2.190	2.200
Lepidocrocite	$Fe_2O_3.H_2O$	1.930	2.210	2.510
Limonite	$2Fe_2O_3.3H_2O$ in part	2.170	2.290	2.310
Goethite	$Fe_2O_3.H_2O$	2.210	2.350	2.350 (Li)
Valentinite	Sb_2O_3	2.180	2.350	2.350
Turgite	$2Fe_2O_3.H_2O$ in part	2.450	2.550	2.550 (Li)
Realgar	AsS	2.460	2.590	2.610 (Li)
Terlinguaite	Hg_2OCl	2.350	2.640	2.670 (Li)
Hutchinsonite	$(Tl, Ag)_2S.PbS.2As_2S_3$	3.078	3.176	3.188
Stibnite	Sb_2S_3	3.194	4.303	4.460

INDEX OF REFRACTION

TABLE 408.—Miscellaneous Biaxial Crystals

Crystal.	Spectrum line.	Index of refraction.			Authority.
		n_α	n_β	n_γ	
Ammonium oxalate, $(NH_4)_2C_2O_4.H_2O$	D	1.4381	1.5475	1.5950	Brio
Ammonium acid tartrate, $(NH_4)H(C_4H_4O_6)$	D	1.5188	1.5614	1.5910	T. and C.*
Ammonium tartrate, $(NH_4)_2C_4H_4O_6$	D	—	1.581	—	Cloisaux
Antipyrin, $C_{11}H_{12}NO_2$	D	1.5697	1.6935	1.7324	Liweh
Citric acid, $C_6H_8O_7.H_2O$	D	1.4932	1.4977	1.5089	Schrauf
Codein, $C_{18}H_{21}NO_3.H_2O$	D	1.5390	1.5435	—	Grailich
Magnesium carbonate, $MgCO_3.3H_2O$	D	1.495	1.501	1.526	Genth
" sulphate, $MgSO_4.7H_2O$	D	1.432	1.455	1.461	Means
" "	Cd, 0.226μ	1.4990	1.5266	1.5326	Borel
" "	H, 0.656μ	1.4307	1.4532	1.4584	"
Potassium bichromate, $K_2Cr_2O_7$	D	1.7202	1.7380	1.8197	Dufet
" chromate, K_2CrO_4	D	—	1.7254	—	T. and C.
" "	red	1.6873	1.722	1.7305	Mallard
" nitrate, KNO_3	D	1.3346	1.5056	1.5064	Schrauf
" sulphate, K_2SO_4	F	1.4976	1.4992	1.5029	T. and C.
" "	D	1.4932	1.4946	1.4980	" " "
" "	C	1.4911	1.4928	1.4959	" " "
Racemic acid, $C_4H_6O_6.H_2O$	yellow	—	1.526	—	Groth
Resorcin, $C_6H_6O_2$	D	—	1.555	—	"
Sodium bichromate, $Na_2Cr_2O_7.2H_2O$	D	1.6610	1.6994	1.7510	Dufet
" acid tartrate, $NaH(C_4H_4O_6).2H_2O$	red	—	1.5332	—	Brio
Sugar (cane), $C_{12}H_{22}O_{11}$	Tl	1.5422	1.5685	1.5734	Calderon
" "	D	1.5397	1.5667	1.5716	"
" "	Li	1.5379	1.5639	1.5693	"
Tartaric acid, $C_4H_6O_6$ (right-)	D	1.4953	1.5353	1.6046	Means
Zinc sulphate, $ZnSO_4.7H_2O$	F	1.4620	1.4860	1.4897	T. and C.
" "	D	1.4568	1.4801	1.4836	" " "
" "	C	1.4544	1.4776	1.4812	" " "

* Topsöe and Christiansen.

TABLE 409.—Miscellaneous Liquids (see also Table 410), Liquefied Gases, Oils, Fats and Waxes

Substance.	Temp. °C	Index for D 0.589μ.	Reference.	Substance.	Temp. °C	Index for D 0.589μ.	Reference.
Liquefied gases:				Oils:			
Br_2	15	1.659	a	Lavendar	20	1.464–1.466	e
Cl_2	14	1.367	b	Linseed	15	1.4820–1.4852	e
CO_2	15	1.195	b	Maize	15.5	1.4757–1.4768	d
C_2N_2	18	1.325	b	Mustard seed	15.5	1.4750–1.4762	d
C_2H_4	6	1.180	b	Neat's foot	15	1.4695–1.4708	e
H_2S	18.5	1.384	b	Olive	15.5	1.4703–1.4718	d
N_2	−190	1.205	c	Palm	60	1.4510	d
NH_3	16.5	1.325	b	Peanut	15.5	1.4723–1.4731	d
NO	−90	1.330	c	Peppermint	20	1.464–1.468	e
N_2O	15	1.194	b	Poppy	15.5	1.4770	d
O_2	−181	1.221	c	Porpoise	25	1.4677	e
SO_2	15.	1.350	b	Rape (Colza)	15.5	1.4748–1.4752	d
HCl	16.5	1.252	b	Seal	25	1.4741	e
HBr	10	1.325	b	Sesame	15.5	1.4742	d
HI	16.5	1.466	b	Soja bean	15.5	1.4760–1.4775	e
Oils:				Sperm	15.5	1.4665–1.4672	e
Almond	15.5	1.4728–1.4753	d	Sunflower	15.5	1.4739	d
Castor	15	1.4799–1.4803	e	Tung	19	1.503	e
Citronella	20	1.47–1.48	e	Whale	40	1.4649	e
Clove	20	1.5301–1.5360	e	Fats and Waxes:			
Cocoanut	15.5	1.4587	d	Beef tallow	40	1.4552–1.4587	e
Cod liver	15	1.4790–1.4833	e	Beeswax	75	1.4398–1.4451	e
Cotton seed	15.5	1.4737–1.4757	d	Carnauba wax	84	1.4520–1.4541	e
Croton	27	1.4757–1.4768	e	Cocoa butter	40	1.4560–1.4518	e
Eucalyptus	20	1.460–1.467	e	Lard	40	1.4584–1.4601	e
Lard	15.5	1.4702–1.4720	d	Mutton tallow	60	1.4510	e

References: (a) Martens; (b) Bleekrode, Pr. Roy. Soc. 37, 339, 1884; (c) Liveing, Dewar, Phil. Mag., 1892–3; (d) Tolman, Munson, Bul. 77, B. of C., Dept. Agriculture, 1005; (e) Seeker, Van Nostrand's Chemical Annual. For the oils of reference d, the average temperature coefficient is 0.000365 per ° C.

TABLE 410

INDEX OF REFRACTION

Indices of Refraction of Liquids Relative to Air

Substance.	Density.	Temp. °C	Indices of refraction. 0.397μ H	0.434μ G′	0.486μ F	0.589μ D	0.656μ C	Authority.
Acetaldehyde, CH_3CHO	0.780	20	—	1.3394	1.3359	1.3316	1.3298	1a
Acetone, CH_3COCH_3	0.791	20	—	1.3678	1.3639	1.3593	1.3573	Means
Aniline, $C_6H_5.NH_2$	1.022	20	—	1.6204	1.6041	1.5863	1.5793	"
Alcohol, methyl, $CH_3.OH$	0.794	20	1.3399	1.3362	1.3331	1.3290	1.3277	"
" ethyl $C_2H_5.OH$	0.808	0	—	1.3773	1.3739	1.3695	1.3677	1b
" "	0.800	20	—	1.3700	1.3666	1.3618	1.3605	Means
" " *dn/dt*	—	20	—	−.0004	−.0004	−.0004	−.0004	2
" n-propyl $C_3H_7.OH$	0.804	20	—	1.3938	1.3901	1.3854	1.3834	1
Benzene, C_6H_6	0.880	20	—	1.5236	1.5132	1.5012	1.4965	Means
" C_6H_6 *dn/dt*	—	20	—	−.0007	−.0006	−.0006	−.0006	"
Bromnaphthalene, $C_{10}H_7Br$	1.487	20	1.7289	1.7041	1.6819	1.6582	1.6495	3
Carbon disulphide, CS_2	1.293	0	1.7175	1.6920	1.6688	1.6433	1.6336	4
" "	1.263	20	1.6994	1.6748	1.6523	1.6276	1.6182	"
" tetrachloride, CCl_4	1.591	20	—	1.4729	1.4676	1.4607	1.4579	1d
Chinolin, C_9H_7N	1.090	20	—	1.6679	1.6470	1.6245	1.6161	1c
Chloral, $CCl_3.CHO$	1.512	20	—	1.4679	1.4624	1.4557	1.4530	1c
Chloroform, $CHCl_3$	1.489	20	1.463	1.458	1.4530	1.4467	1.4443	Means
Decane, $C_{10}H_{22}$	0.728	14.9	—	1.4200	1.4160	1.4108	1.4088	1e
Ether, ethyl, $C_2H_5.O.C_2H_5$	0.715	20	—	1.3607	1.3576	1.3538	1.3515	Means
" " *dn/dt*	—	20	—	−.0006	−.0006	−.0006	−.0006	"
Ethyl nitrate, $C_2H_5.O.NO_3$	1.109	20	—	1.395	1.392	1.3853	1.3830	"
Formic acid, $H.CO_2H$	1.219	20	—	1.3804	1.3764	1.3714	1.3693	1a
Glycerine, $C_3H_8O_3$	1.260	20	—	1.4828	1.4784	1.4730	1.4706	5
Hexane, $CH_3(CH_2)_4CH_3$	0.660	20	—	1.3836	1.3799	1.3754	1.3734	1c
Hexylene, $CH_3(CH_2)_3CH.CH_2$	0.679	23.3	—	1.4059	1.4007	1.3945	1.3920	1c
Methylene iodide CH_2I_2	3.318	20	1.8027	—	1.7692	1.7417	1.7320	Means
" " *dn/dt*	—	20	—	—	−.0007	−.0007	−.0006	"
Naphthalene, $C_{10}H_8$	0.962	98.4	—	—	1.6031	1.5823	1.5746	1f
Nicotine, $C_{10}H_{14}N_2$	1.012	22.4	—	1.5439	—	1.5239	1.5198	1c
Octane, $CH_3(CH_2)_6CH_3$	0.707	15.1	—	1.4097	1.4046	1.4007	1.3987	1e
Oil, almond	0.92	0	—	—	1.4847	1.4782	1.4755	6
anise seed	0.99	15.1	1.6084	—	1.5743	1.5572	1.5508	7
"	0.99	21.4	—	—	1.5647	1.5475	1.5410	8
bitter almond	1.06	20	—	1.5775	1.5623	—	1.5391	5
cassia	—	10	1.7039	—	1.6389	1.6104	1.6007	7
"	—	22.5	1.6985	—	1.6314	1.6026	1.5930	7
cinnamon	1.05	23.5	—	—	1.6508	1.6188	1.6077	8
olive	0.92	0	—	—	1.4825	1.4763	1.4738	6
rock	—	0	—	—	1.4644	1.4573	1.4545	6
turpentine	0.87	10.6	1.4939	—	1.4817	1.4744	1.4715	9
"	0.87	20.7	1.4913	—	1.4793	1.4721	1.4692	8
Pentane, $CH_3(CH_2)_3CH_3$	0.625	15.7	—	1.3645	1.3610	1.3581	1.3570	1e
Phenol, C_6H_5OH	1.060	40.6	—	1.5684	1.5558	1.5425	1.5369	1g
"	1.021	82.7	—	—	1.5356	—	1.5174	1h
Styrene, $C_6H_5CH.CH_2$	0.910	16.6	—	1.5816	1.5659	1.5485	1.5419	1i
Thymol, $C_{10}H_{14}O$	0.982	—	—	—	1.5386	—	1.5228	1h
Toluene, $CH_3.C_6H_5$	0.86	20	—	1.5170	1.5070	1.4955	1.4911	10
Water, H_2O	—	20	1.3435	1.3404	1.3372	1.3330	1.3312	Means
"	—	0	1.3444	1.3413	1.3380	1.3338	1.3319	"
"	—	40	1.3411	1.3380	1.3349	1.3307	1.3290	"
"	—	80	1.3332	1.3302	1.3270	1.3230	1.3313	"

References: 1, Landolt and Börnstein (a, Landolt; b, Korten; c, Brühl; d, Haagen; e, Landolt, Jahn; f, Nasini, Bernheimer; g, Eisenlohr; h, Eykman; i, Auwers, Eisenlohr); 2, Korten; 3, Walter; 4, Ketteler; 5, Landolt; 6, Olds; 7, Baden Powell; 8, Willigen; 9, Fraunhofer; 10, Brühl.

Table 411

INDEX OF REFRACTION

Indices of Refraction for Solutions of Salts and Acids Relative to Air

Substance.	Density.	Temp. C.	C	D	F	H_γ	H	Authority.
			Indices of refraction for spectrum lines.					
(a) Solutions in Water.								
Ammonium chloride	1.067	27°.05	1.37703	1.37936	1.38473	–	1.39336	Willigen.
" "	.025	29.75	.34850	.35050	.35515	–	.36243	"
Calcium chloride .	.398	25.65	.44000	.44279	.44938	–	.46001	"
" "	.215	22.9	.39411	.39652	.40206	–	.41078	"
" "	.143	25.8	.37152	.37369	.37876	–	.38666	"
Hydrochloric acid .	1.166	20.75	1.40817	1.41109	1.41774	–	1.42816	"
Nitric acid	.359	18.75	.39893	.40181	.40857	–	.41961	"
Potash (caustic) . .	.416	11.0	.40052	.40281	.40808	–	.41637	Fraunhofer.
Potassium chloride .	normal solution		.34087	.34278	.34719	1.35049	–	Bender.
" "	double normal		.34982	.35179	.35645	.35994	–	"
" "	triple normal		.35831	.36029	.36512	.36890	–	"
Soda (caustic) . .	1.376	21.6	1.41071	1.41334	1.41936	–	1.42872	Willigen
Sodium chloride . .	.189	18.07	.37562	.37789	.38322	1.38746	–	Schutt.
" "	.109	18.07	.35751	.35959	.36442	.36823	–	"
" "	.035	18.07	.34000	.34191	.34628	.34969	–	"
Sodium nitrate . .	1.358	22.8	1.38283	1.38535	1.39134	–	1.40121	Willigen.
Sulphuric acid . .	.811	18.3	.43444	.43669	.44168	–	.44883	"
" "	.632	18.3	.42227	.42466	.42967	–	.43694	"
" "	.221	18.3	.36793	.37009	.37468	–	.38158	"
" "	.028	18.3	.33663	.33862	.34285	–	.34938	"
Zinc chloride . . .	1.359	26.6	1.39977	1.40222	1.40797	–	1.41738	"
" " . . .	.209	26.4	.37292	.37515	.38026	–	.38845	"
(b) Solutions in Ethyl Alcohol.								
Ethyl alcohol . . .	0.789	25.5	1.35791	1.35971	1.36395	–	1.37094	Willigen.
" "	.932	27.6	.35372	.35556	.35986	–	.36662	"
Fuchsin (nearly saturated)	–	16.0	.3918	.398	.361	–	.3759	Kundt.
Cyanin (saturated) .	–	16.0	.3831	–	.3705	–	.3821	"

Note. — Cyanin in chloroform also acts anomalously; for example, Sieben gives for a 4.5 per cent. solution $\mu_A = 1.4593$, $\mu_B = 1.4695$, μ_F(green) $= 1.4514$, μ_G (blue) $= 1.4554$. For a 9.9 per cent. solution he gives $\mu_A = 1.4902$, μ_F(green) $= 1.4497$, μ_G(blue) $= 1.4597$.

(c) Solutions of Potassium Permanganate in Water.*

Wave-length in cms. × 10^6.	Spectrum line.	Index for 1 % sol.	Index for 2 % sol.	Index for 3 % sol.	Index for 4 % sol.	Wave-length in cms. × 10^6.	Spectrum line.	Index for 1 % sol.	Index for 2 % sol.	Index for 3 % sol.	Index for 4 % sol.
68.7	B	1.3328	1.3342	–	1.3382	51.6	–	1.3368	1.3385	–	–
65.6	C	.3335	.3348	1.3365	.3391	50.0	–	.3374	.3383	1.3386	1.3404
61.7	–	.3343	.3365	.3381	.3410	48.6	F	.3377	–	–	.3408
59.4	–	.3354	.3373	.3393	.3426	48.0	–	.3381	.3395	.3398	.3413
58.9	D	.3353	.3372	–	.3426	46.4	–	.3397	.3402	.3414	.3423
56.8	–	.3362	.3387	.3412	.3445	44.7	–	.3407	.3421	.3426	.3439
55.3	–	.3366	.3395	.3417	.3438	43.4	–	.3417	–	–	.3452
52.7	E	.3363	–	–	–	42.3	–	.3431	.3442	.3457	.3468
52.2	–	.3362	.3377	.3388	–	–	–	–	–	–	–

* According to Christiansen.

Table 412

INDEX OF REFRACTION

Indices of Refraction of Gases and Vapors

A formula was given by Biot and Arago expressing the dependence of the index of refraction of a gas on pressure and temperature. More recent experiments confirm their conclusions. The formula is $n_t - 1 = \frac{n_0 - 1}{1 + at} \cdot \frac{p}{760}$, where n_t is the index of refraction for temperature t, n_0 for temperature zero, a the coefficient of expansion of the gas with temperature, and p the pressure of the gas in millimeters of mercury. For air see Table 413.

(a) Indices of refraction.

Spectrum line.	$10^3 (n-1)$ Air.	Spectrum line.	$10^3 (n-1)$ Air.	Wave-length.	$(n-1)\ 10^3$. Air.	O.	N.	H.
				μ				
A	.2905	M	.2993	.4861	.2951	.2734	.3012	.1406
B	.2911	N	.3003	.5461	.2936	.2717	.2998	.1397
C	.2914	O	.3015	.5790	.2930	.2710	—	.1393
D	.2922	P	.3023	.6563	.2919	.2698	.2982	.1387
E	.2933	Q	.3031	.4360	.2971	.2743	CO_2	.1418
F	.2943	R	.3043	.5462	.2937	.2704	.4506	.1397
G	.2962	S	.3053	.6709	.2918	.2683	.4471	.1385
H	.2978	T	.3064	6.709	.2881	.2643	.4804	.1361
K	.2980	U	.3075	8.678	.2888	.2650	.4579	.1361
L	.2987							

First 4, Cuthbertsons; the rest, Koch, 1909.

(b) The following are compiled mostly from a table published by Brühl (Zeits. für Phys. Chem. vol. 7, pp. 25–27). The numbers are from the results of experiments by Biot and Arago, Dulong, Jamin, Ketteler, Lorenz, Mascart, Chappius, Rayleigh, and Rivière and Prytz. When the number given rests on the authority of one observer the name of that observer is given. The values are for 0° Centigrade and 760 mm pressure.

Substance.	Kind of light.	Indices of refraction and authority.	Substance.	Kind of light.	Indices of refraction and authority.
Acetone . . .	D	1.001079–1.001100	Hydrogen . .	white	1.000138–1.000143
Ammonia . .	white	1.000381–1.000385	" . .	D	1.000132 Burton.
" . .	D	1.000373–1.000379	Hydrogen sulphide . .	D	1.000644 Dulong.
Argon	D	1.000281 Rayleigh.		D	1.000623 Mascart.
Benzene . . .	D	1.001700–1.001823	Methane . . .	white	1.000443 Dulong.
Bromine . . .	D	1.001132 Mascart.	" . . .	D	1.000444 Mascart.
Carbon dioxide	white	1.000449–1.000450	Methyl alcohol.	D	1.000549–1.000623
" "	D	1.000448–1.000454	Methyl ether .	D	1.000891 Mascart.
Carbon disulphide . .	white	1.001500 Dulong.	Nitric oxide . .	white	1.000303 Dulong.
	D	1.001478–1.001485	" " . .	D	1.000297 Mascart.
Carbon monoxide . .	white	1.000340 Dulong.	Nitrogen . . .	white	1.000295–1.000300
	white	1.000335 Mascart.	" . . .	D	1.000296–1.000298
Chlorine . . .	white	1.000772 Dulong.	Nitrous oxide .	white	1.000503–1.000507
" . . .	D	1.000773 Mascart.	" " .	D	1.000516 Mascart.
Chloroform . .	D	1.001436–1.001464	Oxygen . . .	white	1.000272–1.000280
Cyanogen . .	white	1.000834 Dulong.	" . . .	D	1.000271–1.000272
" . .	D	1.000784–1.000825	Pentane . . .	D	1.001711 Mascart.
Ethyl alcohol .	D	1.000871–1.000885	Sulphur dioxide	white	1.000665 Dulong.
Ethyl ether . .	D	1.001521–1.001544	" "	D	1.000686 Ketteler.
Helium . . .	D	1.000036 Ramsay.	Water	white	1.000261 Jamin.
Hydrochloric acid . . .	white	1.000449 Mascart.	"	D	1.000249–1.000259
	D	1.000447 "			

TABLE 413

INDEX OF REFRACTION

TABLE 413.—Index of Refraction of Air (15°C, 76 cm)

Corrections for reducing wave lengths and frequencies in air (15° C, 76 cm) to vacuo.

The indices were computed from the Cauchy formula $(n-1)10^7 = 2726.43 + 12.288/(\lambda^2 \times 10^{-8}) + 0.3555/(\lambda^4 \times 10^{-16})$. For 0° C and 76 cm the constants of the equation become 2875.66, 13.412 and 0.3777 respectively, and for 30° C and 76 cm, 2589.72, 12.259 and 0.2576. Sellmeier's formula for but one absorption band closely fits the observations: $n^2 = 1 + 0.00057378\lambda^2/(\lambda^2 - 595260)$. If $n-1$ were strictly proportional to the density, then $(n-1)_0/(n-1)_t$ would equal $1 + \alpha t$ where α should be 0.00367. The following values of α were found to hold:

λ	0.85μ	0.75μ	0.65μ	0.55μ	0.45μ	0.35μ	0.25μ
α	0.003672	0.003674	0.003678	0.003685	0.003700	0.003738	0.003872

The indices are for dry air (0.05 ± % CO_2). Corrections to reduce to dry air the indices for moist air may be made for any wave-length by Lorenz's formula, $+ 0.000041(m/760)$, where m is the vapor pressure in mm. The corresponding frequencies in waves per cm and the corrections to reduce wave-lengths and frequencies in air at 15° C and 76 cm pressure to vacuo are given. E.g., a light wave of 5000 Angstroms in dry air at 15° C, 76 cm becomes 5001.391 A in vacuo; a frequency of 20,000 waves per cm correspondingly becomes 19994.44. Meggers and Peters, Bul. Bureau of Standards, 14, p. 731, 1918.

Wave-length, λ Angstroms.	Dry air $(n-1) \times 10^7$ 15° C 76 cm	Vacuo correction for λ in air $(n\lambda - \lambda)$. Add.	Frequency waves per cm $\frac{1}{\lambda}$ in air.	Vacuo correction for $\frac{1}{\lambda}$ in air $\left(\frac{1}{n\lambda} - \frac{1}{\lambda}\right)$. Subtract.
2000	3256	0.651	50,000	16.27
2100	3188	0.670	47,619	15.18
2200	3132	0.689	45,454	14.23
2300	3086	0.710	43,478	13.41
2400	3047	0.731	41,666	12.69
2500	3014	0.754	40,000	12.05
2600	2986	0.776	38,461	11.48
2700	2962	0.800	37,037	10.97
2800	2941	0.824	35,714	10.50
2900	2923	0.848	34,482	10.08
3000	2907	0.872	33,333	9.69
3100	2893	0.897	32,258	9.33
3200	2880	0.922	31,250	9.00
3300	2869	0.947	30,303	8.69
3400	2859	0.972	29,411	8.41
3500	2850	0.998	28,571	8.14
3600	2842	1.023	27,777	7.89
3700	2835	1.049	27,027	7.66
3800	2829	1.075	26,315	7.44
3900	2823	1.101	25,641	7.24
4000	2817	1.127	25,000	7.04
4100	2812	1.153	24,390	6.86
4200	2808	1.179	23,809	6.68
4300	2803	1.205	23,255	6.52
4400	2799	1.232	22,727	6.36
4500	2796	1.258	22,222	6.21
4600	2792	1.284	21,739	6.07
4700	2789	1.311	21,276	5.93
4800	2786	1.338	20,833	5.80
4900	2784	1.364	20,406	5.68
5000	2781	1.391	20,000	5.56
5100	2779	1.417	19,607	5.45
5200	2777	1.444	19,230	5.34
5300	2775	1.471	18,867	5.23
5400	2773	1.497	18,518	5.13

Wave-length, λ Angstroms.	Dry air $(n-1) \times 10^7$ 15° C 76 cm	Vacuo correction for λ in air $(n\lambda - \lambda)$. Add.	Frequency waves per cm $\frac{1}{\lambda}$ in air.	Vacuo correction for $\frac{1}{\lambda}$ in air $\left(\frac{1}{n\lambda} - \frac{1}{\lambda}\right)$. Subtract.
5500	2771	1.524	18,181	5.04
5600	2769	1.551	17,857	4.94
5700	2768	1.578	17,543	4.85
5800	2766	1.604	17,241	4.77
5900	2765	1.631	16,949	4.68
6000	2763	1.658	16,666	4.60
6100	2762	1.685	16,393	4.53
6200	2761	1.712	16,129	4.45
6300	2760	1.739	15,873	4.38
6400	2759	1.766	15,625	4.31
6500	2758	1.792	15,384	4.24
6600	2757	1.819	15,151	4.18
6700	2756	1.846	14,925	4.11
6800	2755	1.873	14,705	4.05
6900	2754	1.900	14,492	3.99
7000	2753	1.927	14,285	3.93
7100	2752	1.954	14,084	3.88
7200	2751	1.981	13,888	3.82
7300	2751	2.008	13,698	3.77
7400	2750	2.035	13,513	3.72
7500	2749	2.062	13,333	3.66
7600	2749	2.089	13,157	3.62
7700	2748	2.116	12,987	3.57
7800	2748	2.143	12,820	3.52
7900	2747	2.170	12,658	3.48
8000	2746	2.197	12,500	3.43
8100	2746	2.224	12,345	3.39
8250	2745	2.265	12,121	3.33
8500	2744	2.332	11,764	3.23
8750	2743	2.400	11,428	3.13
9000	2742	2.468	11,111	3.05
9250	2741	2.536	10,810	2.96
9500	2740	2.604	10,526	2.88
9750	2740	2.671	10,256	2.81
10000	2739	2.739	10,000	2.74

MEDIA FOR DETERMINATIONS OF REFRACTIVE INDICES WITH THE MICROSCOPE

TABLE 414.—Liquids, n_D (0.589μ) = 1.74 to 1.87

In 100 parts of methylene iodide at 20° C the number of parts of the various substances indicated in the following table form saturated solutions having the refractive indices specified. When ready for use the liquids can be mixed to give intermediate refractions. Commercial iodoform (CHI_3) powder is not suitable, but crystals from a solution of the powder in ether may be used, or the crystalized product may be bought. A fragment of tin in the liquids containing the SnI_4 will prevent discoloration.

CHI_3.	SnI_4.	AsI_3.	SbI_3.	S.	n_{na} at 20°.
			12		1.764
	25				1.783
	25		12		1.806
	30			6	1.820
	27	13	7		1.826
40	27	16			1.842
	31	14	8	10	1.853
35	31	16	8	10	1.868

TABLE 415.—Resinlike Substances, n_D (0.589μ) = 1.68 to 2.10

Piperine, an inexpensive alkaloid, comes in very pure straw-colored crystals. Melted it dissolves the tri-iodides of Sb and As very freely. The solutions are fluid at slightly above 100° and when cold, resinlike. Three parts antimony iodide to one part of arsenic iodide with varying proportions of piperine are easier to manipulate than one containing either iodide alone. In preparing, the constituents, in powder of about 1 mm grain, should be weighed out and then fused *over,* not *in,* a low flame. Three-inch test tubes are suitable.

Per cent Iodides.	00.	10.	20.	30.	40.	50.	60.	70.	80.
Index of refraction	1.683	1.700	1.725	1.756	1.794	1.840	1.897	1.968	2.050

TABLE 416.—Permanent Standard Resinous Media, n_D (0.589μ) = 1.546 to 1.682

Any proportions of piperine and rosin form a homogeneous fusion which cools to a transparent resinous mass. On account of the strong dispersion of piperine the refractive indices of minerals apparently matched with those of mixtures rich in this constituent are 0.005 to 0.01 too low. To correct this error a screen made of a thin film of 7 per cent antimony iodide and 93 per cent piperine should be used over the eye-piece. Any amber-colored rosin in lumps is suitable.

Per cent Rosin.	00.	10.	20.	30.	40.	50.	60.	70.	80.	90.	100.
Index of refraction	1.683	1.670	1.657	1.643	1.631	1.618	1.604	1.590	1.575	1.560	1.544

All taken from Merwin, Journ. Washington Acad. Sci. 3, 35, 1913.

TABLE 417.—Substances, n_D = 1.39 to 1.75

	n		n		n		n
n-Heptane	1.39	p-Xylene	1.50	o-Toluidine	1.57	α-Chloronaphthalene	1.63
Octylene	1.41	Chlorobenzene	1.53	o-Bromophenol	1.58	α-Bromonaphthalene	1.66
Cyclohexane	1.44	Eugenol	1.54	Bromoform	1.59	α-Iodonaphthalene	1.69
d-Limonene	1.47	Nitrobenzene	1.55	Quinaldine	1.61	Methylene iodide	1.75
		Anethole	1.56	Iodobenzene	1.62		

According to Fresnel, the amount of light reflected by the surface of a transparent medium $= \frac{1}{2}(A+B) = \frac{1}{2}\left\{\frac{\sin^2(i-r)}{\sin^2(i+r)} + \frac{\tan^2(i-r)}{\tan^2(i+r)}\right\}$; A is the amount polarized in the plane of incidence; B is that polarized perpendicular to this; i and r are the angles of incidence and refraction.

TABLE 418.—Light reflected when $i = 0°$ or Incident Light is Normal to Surface $(n-1)^2/(n+1)^2$

n.	$\frac{1}{2}(A+B)$.	n.	$\frac{1}{2}(A+B)$.	n.	$\frac{1}{2}(A+B)$.	n.	$\frac{1}{2}(A+B)$.
1.00	0.00	1.4	2.78	2.0	11.11	5.	44.44
1.02	0.01	1.5	4.00	2.25	14.06	5.83	50.00
1.05	0.06	1.6	5.33	2.5	18.37	10.	66.67
1.1	0.23	1.7	6.72	2.75	22.89	100.	96.08
1.2	0.83	1.8	8.16	3.	25.00	∞	100.00
1.3	1.70	1.9	9.63	4.	36.00		

TABLE 419.—Light reflected when n is near Unity or equals $1 + dn$

i.	A.	B.	$\frac{1}{2}(A+B)$.	$\frac{A-B}{A+B}$.*
0°	1.000	1.000	1.000	0.0
5	1.015	.985	1.000	1.5
10	1.063	.939	1.001	6.2
15	1.149	.862	1.005	14.3
20	1.282	.752	1.017	26.0
25	1.482	.612	1.047	41.5
30	1.778	.444	1.111	60.0
35	2.221	.260	1.240	79.1
40	2.904	.088	1.496	94.5
45	4.000	.000	2.000	100.0
50	5.857	.176	3.016	94.5
55	9.239	1.081	5.160	79.1
60	16.000	4.000	10.000	60.0
65	31.346	12.952	22.149	41.5
70	73.079	42.884	57.981	26.0
75	222.85	167.16	195.00	14.3
80	1099.85	971.21	1035.53	6.2
85	17330.64	16808.08	17069.36	1.5
90	∞	∞	∞	0.0

The values for A and B are strictly $(dn^2/4) \sec^4 i$ and $(dn^2/4)(1 - \tan^2 i)$; In columns 2, 3, and 4 $dn^2/4$ is omitted.

TABLE 420.—Light reflected when $n = 1.55$

i.	r.	A.	B.	dA.†	dB.†	$\frac{1}{2}(A+B)$.	$\frac{A-B}{A+B}$.*
° ′	° ′						
0	0 0.0	4.65	4.65	0.130	0.130	4.65	0.0
5	3 13.4	4.70	4.61	.131	.129	4.65	1.0
10	6 25.9	4.84	4.47	.135	.126	4.66	4.0
15	9 36.7	5.09	4.24	.141	.121	4.66	9.1
20	12 44.8	5.45	3.92	.150	.114	4.68	16.4
25	15 49.3	5.95	3.50	.161	.105	4.73	25.9
30	18 49.1	6.64	3.00	.175	.094	4.82	37.8
35	21 43.1	7.55	2.40	.191	.081	4.98	51.7
40	24 30.0	8.77	1.75	.210	.066	5.26	66.7
45	27 8.5	10.38	1.08	.233	.049	5.73	81.2
50	29 37.1	12.54	0.46	.263	.027	6.50	92.9
55	31 54.2	15.43	0.05	.303	.007	7.74	99.3
60	33 58.1	19.35	0.12	.342	−.013	9.73	98.8
65	35 47.0	24.69	1.13	.375	−.032	12.91	91.2
70	37 19.1	31.99	4.00	.400	−.050	18.00	77.7
75	38 32.9	42.00	10.38	.410	−.060	26.19	61.8
80	39 26.8	55.74	23.34	.370	−.069	39.54	41.0
82 30	39 45.9	64.41	34.04	.320	−.067	49.22	30.8
85 0	39 59.6	74.52	49.03	.250	−.061	61.77	20.6
86 0	40 3.6	79.02	56.62	.209	−.055	67.82	16.5
87 0	40 6.7	83.80	65.32	.163	−.046	74.56	12.4
88 0	40 8.9	88.88	75.31	.118	−.036	82.10	8.3
89 0	40 10.2	94.28	86.79	.063	−.022	90.54	4.1
90 0	40 10.7	100.00	100.00	.000	−.000	100.00	0.0

Angle of total polarization $= 57° 10'.3$, $A = 16.99$.

* This column gives the degree of polarization † Columns 5 and 6 furnish a means of determining A and B for other values of n. They represent the change in these quantities for a change of n of 0.01.

Taken from E. C. Pickering's "Applications of Fresnel's Formula for the Reflection of Light."

TABLE 421

OPTICAL CONSTANTS OF METALS

Two constants are required to characterize a metal optically, the refractive index, n, and the absorption index, k, the latter of which has the following significance: the amplitude of a wave after travelling one wave-length, λ^1 measured in the metal, is reduced in the ratio[1] $1 : e^{-2\pi k}$ or for any distance d, $1 : e^{-\frac{2\pi dk}{\lambda^1}}$; for the same wave-length measured in air this ratio becomes $1 : e^{-\frac{2\pi dnk}{\lambda^1}}$. nk is sometimes called the extinction coefficient. Plane polarized light reflected from a polished metal surface is in general elliptically polarized because of the relative change in phase between the two rectangular components vibrating in and perpendicular to the plane of incidence. For a certain angle, $\bar{\phi}$ (principal incidence) the change is 90° and if the plane polarized incident beam has a certain azimuth $\bar{\psi}$ (Principal azimuth) circularly polarized light results. Approximately, (Drude, Annalen der Physik, 36, p. 546, 1889),

$$k = \tan 2\bar{\psi}\,(1 - \cot^2\bar{\phi}) \text{ and } n = \frac{\sin\bar{\phi}\tan\bar{\phi}}{(1+k^2)^{\frac{1}{2}}}\,(1 + \tfrac{1}{2}\cot^2\bar{\phi}).$$

For rougher approximations the factor in parentheses may be omitted. R = computed percentage reflection.

(The points have been so selected that a smooth curve drawn through them very closely indicates the characteristics of the metal.)

Metal.	λ	$\bar{\phi}$	$\bar{\psi}$	Computed.				Authority.
				n	k	nk	R	
	μ						%	
Cobalt	0.231	64°31′	29°39	1.10	1.30	1.43	32.	Minor.
	.275	70 22	29 59	1.41	1.52	2.14	46.	"
	.500	77 5	31 53	1.93	1.93	3.72	66.	"
	.650	79 0	31 25	2.35	1.87	4.40	69.	Ingersoll.
	1.00	81 45	29 6	3.63	1.58	5.73	73.	"
	1.50	83 21	26 18	5.22	1.29	6.73	75.	"
	2.25	83 48	26 5	5.65	1.27	7.18	76.	"
Copper	.231	65 57	26 14	1.39	1.05	1.45	29.	Minor.
	.347	65 6	28 16	1.19	1.23	1.47	32.	"
	.500	70 44	33 46	1.10	2.13	2.34	56.	"
	.650	74 16	41 30	0.44	7.4	3.26	86.	Ingersoll.
	.870	78 40	42 30	0.35	11.0	3.85	91.	"
	1.75	84 4	42 30	0.83	11.4	9.46	96.	"
	2.25	85 13	42 30	1.03	11.4	11.7	97.	"
	4.00	87 20	42 30	1.87	11.4	21.3		Först.-Fréed.
	5.50	88 00	41 50	3.16	9.0	28.4		" "
Gold	1.00	81 45	44 00	0.24	28.0	6.7		" "
	2.00	85 30	43 56	0.47	26.7	12.5		" "
	3.00	87 05	43 50	0.80	24.5	19.6		" "
	5.00	88 15	43 25	1.81	18.1	33.		" "
Iridium	1.00	82 10	29 15	3.85	1.60	6.2		" "
	2.00	83 10	29 40	4.30	1.66	7.1		" "
	3.00	81 40	30 40	3.33	1.79	6.0		" "
	5.00	79 00	32 20	2.27	2.03	4.6		" "
Nickel	0.420	72 20	31 42	1.41	1.79	2.53	54.	Tool.
	0.589	76 1	31 41	1.79	1.86	3.33	62.	Drude.
	0.750	78 45	32 6	2.19	1.99	4.36	70.	Ingersoll.
	1.00	80 33	32 2	2.63	2.00	5.26	74.	"
	2.25	84 21	33 30	3.95	2.33	9.20	85.	"
Platinum	1.00	75 30	37 00	1.14	3.25	3.7		Först.-Fréed.
	2.00	74 30	39 50	0.70	5.06	3.5		" "
	3.00	73 50	41 00	0.52	6.52	3.4		" "
	5.00	72 00	42 10	0.34	9.01	3.1		" "
Silver	0.226	62 41	22 16	1.41	0.75	1.11	18.	Minor.
	.293	63 14	18 56	1.57	0.62	0.97	17.	"
	.316	52 28	15 38	1.13	0.38	0.43	4.	"
	.332	52 1	37 2	0.41	1.61	0.65	32.	"
	.395	66 36	43 6	0.16	12.32	1.91	87.	"
	.500	72 31	43 29	0.17	17.1	2.94	93.	"
	.589	75 35	43 47	0.18	20.6	3.64	95.	"
	.750	79 26	44 6	0.17	30.7	5.16	97.	Ingersoll.
	1.00	82 0	44 2	0.24	29.0	6.96	98.	"
	1.50	84 42	43 48	0.45	23.7	10.7	98.	"
	2.25	86 18	43 34	0.77	19.9	15.4	99.	"
	3.00	87 10	42 40	1.65	12.2	20.1		Först.-Fréed.
	4.50	88 20	41 10	4.49	7.42	33.3		" "
Steel	0.226	66 51	28 17	1.30	1.26	1.64	35.	Minor.
	.257	68 35	28 45	1.38	1.35	1.86	40.	"
	.325	69 57	30 9	1.37	1.53	2.09	45.	"
	.500	75 47	29 2	2.09	1.50	3.14	57.	"
	.650	77 48	27 9	2.70	1.33	3.59	59.	Ingersoll.
	1.50	81 48	28 51	3.71	1.55	5.75	73.	"
	2.25	83 22	30 36	4.14	1.79	7.41	80.	"

Drude, Annalen der Physik und Chemie, 39, p. 481, 1890; 42, p. 186, 1891; 64, p. 159, 1898. Minor, Annalen der Physik, 10, p. 581, 1903. Tool, Physical Review, 31, p. 1, 1910. Ingersoll, Astrophysical Journal, 32, p. 265, 1910; Försterling and Fréedericksz, Annalen der Physik, 40, p. 201, 1913.

TABLE 422.—Optical Constants of Metals (Additional Data)

Metal.	λ.	n.	k.	R.	Ref.
	μ				
Al.*	0.589	1.44	5.32	83	1
Sb.*	.589	3.04	4.94	70	1
Bi.†‡	white	2.26	–	–	2
Cd.*	.589	1.13	5.01	85	1
Cr.*	.579	2.97	4.85	70	3
Cb.*	.579	1.80	2.11	41	3
Au.†	.257	0.92	1.14	28	4
	.441	1.18	1.85	42	4
	.589	0.47	2.83	82	4
I. crys.	.589	3.34	0.57	30	4
Ir.*	.579	2.13	4.87	75	3
Fe.§	.257	1.01	0.88	16	4
	.441	1.28	1.37	28	4
	.589	1.51	1.63	33	4
Pb.*	.589	2.01	3.48	62	1
Mg.*	.589	0.37	4.42	93	1
Mn.*	.579	2.49	3.89	64	3
Hg. (liq.)	.326	0.68	2.26	66	4
	.441	1.01	3.42	74	4
	.589	1.62	4.41	75	4
	.668	1.72	4.70	77	4
Pd.*	.579	1.62	3.41	65	3
Pt.†	.257	1.17	1.65	37	4
	.441	1.94	3.16	58	4
	.589	2.63	3.54	59	4
	.668	2.91	3.66	59	4
Ni.*	.275	1.09	1.16	24	4
	.441	1.16	1.23	25	4
	.589	1.30	1.97	43	4

Metal.	λ.	n.	k.	R.	Ref.
	μ				
Rh.*	0.579	1.54	4.67	78	3
Se.‡	.400	2.94	2.31	44	5
	.490	3.12	1.49	35	5
	.589	2.93	0.45	25	5
	.760	2.60	0.06	20	5
Si.*	.589	4.18	0.09	38	6
	1.25	3.67	0.08	33	6
	2.25	3.53	0.08	31	6
Na. (liq.)	.589	.004	2.61	99	1
Ta.*	.579	2.05	2.31	44	3
Sn.*	.589	1.48	5.25	82	1
W.*	.579	2.76	2.71	49	3
V.*	.579	3.03	3.51	58	3
Zn.*	.257	0.55	0.61	20	4
	.441	0.93	3.19	73	4
	.589	1.93	4.66	74	4
	.668	2.62	5.08	73	4

λ = wave-length, n = refraction index. k = absorption index, R = reflection.

(1) Drude, see Table 421; (2) Kundt, prism used, Ann. der Physik und Chemie, 34, p. 477, 36, p. 824, 1889; (3) v. Wartenberg, Verh. deutsch. Physik. Ges. 12, p. 105, 1910; (4) Meier, Annales der Physik, 10, p. 581, 1903; (5) Wood, Phil. Mag. (6), 3, 607, 1902; (6) Ingersoll, *see* Table 421.

* solid, † electrolytic, ‡ prism, § deposited as film in vacuo.

TABLE 423.—Reflecting Power of Metals (See page 379)

Wave-length	Al.	Sb.	Cd.	Co.	Graph-ite.	Ir.	Mg.	Mo.	Pd.	Rh.	Si.	Ta.	Te.	Sn.	W	Va.	Zn.
μ	Per cents.																
.5	–	–	–	–	22	–	72	46	–	76	34	38	–	–	49	57	–
.6	–	53	–	–	24	–	73	48	–	77	32	45	49	–	51	58	–
.8	–	54	–	–	25	–	74	52	–	81	29	64	48	–	56	60	–
1.0	71	55	72	67	27	78	74	58	72	84	28	78	50	54	62	61	80
2.0	82	60	87	72	35	87	77	82	81	91	28	90	52	61	85	69	92
4.0	92	68	96	81	48	94	84	90	88	92	28	93	57	72	93	79	97
7.0	96	71	98	93	54	95	91	93	94	94	28	94	68	81	95	88	98
10.0	98	72	98	97	59	96	–	94	97	95	28	–	–	84	96	–	98
12.0	98	–	99	97	–	96	–	95	97	–	–	95	–	85	96	–	99

Coblentz, Bulletin Bureau of Standards, 2, p. 457, 1906, 7, p. 197, 1911. The surfaces of some of the samples were not perfect so that the corresponding values have less weight. The methods for polishing the various metals are described in the original articles. The following more recent values are given by Coblentz and Emerson, Bul. Bur. Stds. 14, p. 207, 1917; Stellite, an exceedingly hard and untarnishable alloy of Co, Cr, Mo, Mn, and Fe (C, Si, S, P) was obtained from the Haynes Stellite Co, Kokomo, Indiana.

Wave-length, μ,	.15	.20	.30	.50	.75	1.00	2.00	3.00	4.00	5.00	9.00
Tungsten,	—	—	—	.50	.52	.576	.900	.943	.948	.953	—
Stellite,	.32	.42	.50	.64	.67	.689	.747	.792	.825	.848	.880

TABLE 424.—Reflecting Power of Metals

Perpendicular Incidence and Reflection (See also Tables 426-428)

The numbers give the per cents of the incident radiation reflected.

Wave-length, μ.	Silver-backed Glass.	Mercury-backed Glass.	Mach's Magnalium. $69Al + 31Mg$.	Brandes-Schünemann Alloy. $32Cu + 34Sn + 29Ni + 5Fe$.	Ross' Speculum Metal. $68.2Cu + 31.8Sn$.	Nickel. *Electrolytically Deposited.*	Copper. *Electrolytically Deposited.*	Steel. *Untempered.*	Copper. *Commercially Pure.*	Platinum. *Electrolytically Deposited.*	Gold. *Electrolytically Deposited.*	Brass. *(Trowbridge).*	Silver. *Chemically Deposited.*
.251	–	–	67.0	35.8	29.9	37.8	–	32.9	25.9	33.8	38.8	–	34.1
.288	–	–	70.6	37.1	37.7	42.7	–	35.0	24.3	38.8	34.0	–	21.2
.305	–	–	72.2	37.2	41.7	44.2	–	37.2	25.3	39.8	31.8	–	9.1
.316	–	–	–	–	–	–	–	–	–	–	–	–	4.2
.326	–	–	75.5	39.3	–	45.2	–	40.3	24.9	41.4	28.6	–	14.6
.338	–	–	–	–	–	46.5	–	–	–	–	–	–	55.5
.357	–	–	81.2	43.3	51.0	48.8	–	45.0	27.3	43.4	27.9	–	74.5
.385	–	–	83.9	44.3	53.1	49.6	–	47.8	28.6	45.4	27.1	–	81.4
.420	–	–	83.3	47.2	56.4	56.6	–	51.9	32.7	51.8	29.3	–	86.6
.450	85.7	72.8	83.4	49.2	60.0	59.4	48.8	54.4	37.0	54.7	33.1	–	90.5
.500	86.6	70.9	83.3	49.3	63.2	60.8	53.3	54.8	43.7	58.4	47.0	–	91.3
.550	88.2	71.2	82.7	48.3	64.0	62.6	59.5	54.9	47.7	61.1	74.0	–	92.7
.600	88.1	69.9	83.0	47.5	64.3	64.9	83.5	55.4	71.8	64.2	84.4	–	92.6
.650	89.1	71.5	82.7	51.5	65.4	66.6	89.0	56.4	80.0	66.5	88.9	–	94.7
.700	89.6	72.8	83.3	54.9	66.8	68.8	90.7	57.6	83.1	69.0	92.3	–	95.4
.800	–	–	84.3	63.1	–	69.6	–	58.0	88.6	70.3	94.9	–	96.8
1.0	–	–	84.1	69.8	70.5	72.0	–	63.1	90.1	72.9	–	–	97.0
1.5	–	–	85.1	79.1	75.0	78.6	–	70.8	93.8	77.7	97.3	–	98.2
2.0	–	–	86.7	82.3	80.4	83.5	–	76.7	95.5	80.6	96.8	91.0	97.8
3.0	–	–	87.4	85.4	86.2	88.7	–	83.0	97.1	88.8	–	93.7	98.1
4.0	–	–	88.7	87.1	88.5	91.1	–	87.8	97.3	91.5	96.9	95.7	98.5
5.0	–	–	89.0	87.3	89.1	94.4	–	89.0	97.9	93.5	97.0	95.9	98.1
7.0	–	–	90.0	88.6	90.1	94.3	–	92.9	98.3	95.5	98.3	97.0	98.5
9.0	–	–	90.6	90.3	92.2	95.6	–	92.9	98.4	95.4	98.0	97.8	98.7
11.0	–	–	90.7	90.2	92.9	95.9	–	94.0	98.4	95.6	98.3	96.6	98.8
14.0	–	–	92.2	90.3	93.6	97.2	–	96.0	97.9	96.4	97.9	–	98.3

Based upon the work of Hagen and Rubens, Ann. der Phys (1) 352, 1900; (8) 1, 1902; (11) 873, 1903. Taken partly from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

TABLE 425.—Percentage Diffuse Reflection from Miscellaneous Substances

Wave-length μ	Lamp-blacks. Paint.	Lamp-blacks. Rosin	Lamp-blacks. Sperm candle.	Lamp-blacks. Acetylene	Lamp-blacks. Camphor.	Pt. black electrol.	Green leaves.	Lead oxide.	Al. oxide.	Zinc oxide.	White Paper.	Lead carbonate.	Asphalt.	Black velvet.	Black felt.	Red brick.
*.60	3.2						25.	52.	84.	82.		89.	15.	1.8	14.	30.
*.95	3.4	1.3	1.1	0.6	1.3	1.1			88.	86.	75.	93.			21.	
4.4	3.2	1.3	.9	.8	1.2	1.4		51.	21.	8.	18	29.		3.7		
8.8	3.8		1.3	1.2	1.6	2.1		26.	2.	3.	5.	11.		2.7		12.
24.0	4.4	3.0	4.0	2.1	5.7	4.2		10.	6.	5.		7.				

*Not monochromatic (max.) means from Coblentz, J. Franklin Inst. 1912. Bulletin Bureau of Standards, 9, p. 283, 1912, contains many other materials.

TABLE 426.—Percentage Refleotion from Metals, Violet End of Spectrum

(Coblentz, Stair, Bur. Standards Journ. Res., 2, 343, 1929.)

Wave length in μ	.05	.10	.15	.20	.25	.30	.35	.40	.50	.60
Ni electroplated	..	..	..	..	40	44	51	53	56	(60)
" vac. fused	..	..	..	..	48	42	45	52	62	64
Ag (min. 7%, 33μ)	..	..	..	..	30	16	71	88	92	(94)
Stellite (Co, Cr, Mo)	..	..	..	..	46	49	55	60	64	(68)
Stainless steel, 13% Cr	..	..	..	..	40	47	52	56	59	(60)
Cobalt	..	..	..	..	43	46	52	58	62	(67)
Speculum	..	..	..	..	31	41	50	56	60	(62)
Beryllium (98.7%)	46	53	67	79	84	87	..	..	..	..
Chromium on steel	69	63	65	71	78	82	86	88	..	..

TABLE 427.—Ultra-violet Reflecting Power of Some Metals

(Coblentz, Stair, Bur. Standards Journ. Res., 4, 189, 1930.)

	0.250μ	.300	.350	.400	.450	.500	.550	.600
Aluminum, cast, polished	.43	.45	.54	.62	.68	.72	.73	.74
" rolled	.21	.28	.34	.41	.46	.50	.53	.56
Rhodium	.30	.37	.44	.50	.53	.57	.58	.59
Tin, polished	.33	.38	.45	.52	.60	.67	.72	.73
Duralumin	.24	.31	.44	.46	.46	.46	.46	.46
" tarnished to	.20	.26	.32					

TABLE 428.—Infra-red Reflectivity of Tungsten (Temperature Variation)

Three tungsten mirrors were used, — a polished Coolidge X-ray target and two polished flattened wires mounted in evacuated soft-glass bulbs with terminals for heating electrically. Weniger and Pfund, J. Franklin Inst.

Wave-length in μ.	Absolute reflectivity at room temperature in per cent.	Per cent increase in reflectivity in going from room temperature to			
		1377° K.	1628° K.	1853° K	2056° K.
0.67	51	+6.0	+7.4	+8.7	+9.8
0.80	55	—	—	—	+8.2
1.27	70	0.0	0.0	0.0	0.0
1.90	83	−6.6	−8.2	−9.6	−11.0
2.00	85	−7.5	−9.3	−10.9	−12.3
2.90	92	−7.7	−9.4	−11.1	−12.5
4.00	93	—	—	—	−12.5

See also Weniger and Pfund, Phys. Rev. 15, p. 427, 1919.

TABLE 429.—Percentage Reflecting Power of Dry Powdered Pigments

Taken from "The Physical Basis of Color Technology," Luckiesh, J. Franklin Inst., 1917. The total reflecting power depends on the distribution of energy in the illuminant and is given in the last three columns for noon sun, blue sky, and for a 7.9 lumens/watt tungsten filament.

Spectrum color.	Violet.	Blue.		Green.			Yellow.		Orange.			Red.			Noon sun.	Sky light.	Tungsten lamp.
Wave-length in μ	0.44	0.46	0.48	0.50	0.52	0.54	0.56	0.58	0.60	0.62	0.64	0.66	0.68	0.70			
American vermilion	8	6	5	5	6	6	9	11	24	39	53	61	66	65	14	12	12
Venetian red	5	5	5	5	5	6	7	12	19	24	28	30	32	32	11	10	13
Tuscan red	7	7	7	8	8	8	8	12	16	18	20	22	23	24	11	10	12
Indian red	8	7	7	7	7	7	7	11	15	18	20	22	23	24	10	9	11
Burnt sienna	4	4	4	4	5	6	9	14	18	20	21	23	24	25	11	9	13
Raw sienna	12	13	13	13	18	26	35	43	46	46	45	44	45	43	33	30	37
Golden ochre	22	22	23	27	40	53	63	71	75	74	73	73	73	72	58	55	63
Chrome yellow ochre	8	9	7	7	10	19	30	46	60	62	66	82	81	80	33	29	40
Yellow ochre	20	20	21	24	32	42	53	63	64	61	60	59	59	59	49	46	53
Chrome yellow medium	5	5	6	8	18	48	66	75	78	79	81	81	81	81	54	50	63
Chrome yellow light	13	13	18	30	56	82	88	89	90	89	88	87	85	84	76	70	82
Chrome green light	10	10	14	23	26	23	20	17	14	11	9	8	7	6	19	19	18
Chrome green medium	7	7	10	21	21	17	13	11	9	7	6	6	6	5	14	14	12
Cobalt blue	59	58	49	35	23	15	11	10	10	10	11	15	20	25	16	18	13
Ultramarine blue	67	54	38	21	10	6	4	3	3	4	5	7	10	17	7	10	6

TABLE 430.—Infra-red Diffuse Percentage Reflecting Powers of Dry Pigments

Wave-length in μ	Co_2O_3	CuO	Cr_2O_3	PbO	Fe_2O_3	Y_2O_3	$PbCrO_4$	Al_2O_3	ThO_2	ZnO	MgO	CaO	ZrO_2	$PbCO_3$	$MgCO_3$	White lead paint	Zn oxide paint
0.60 *	3	—	27	52	26	74	70	84	86	82	86	85	86	88	85	76	68
0.95 *	4	24	45	—	41	—	—	88	—	86	—	—	84	93	89	79	72
4.4	14	15	33	51	30	34	41	21	47	8	16	22	23	29	11	—	—
8.8	13	—	5	26	4	11	5	20	7	3	2	4	5	10	4	—	—
24.0	6	4	8	10	9	10	7	6	10	5	9	6	5	7	9	—	—

* Non-monochromatic means from Coblentz, Bul. Bureau Standards 9, p. 283, 1912.

For the REFLECTING (and transmissive) power of ROUGHENED SURFACES at various angles of incidence, see Gorton, Physical Review, 7, p. 66, 1916. A surface of plate glass, ground uniformly with the finest emery and then silvered, used at an angle of 75°, reflected 90 per cent at 4μ, approached 100 for longer waves, only 10 at 1μ, less than 5 in the visible red and approached 0 for shorter waves. Similar results were obtained with a plate of rock salt for transmitted energy when roughened merely by breathing on it. In both cases the finer the surface, the more suddenly it cuts off the short waves.

TABLE 431.—Reflectivity of Snow, Sand, Etc.

(Hulburt, Journ. Opt. Soc. Amer., 17, 23, 1928.)

	Maine sand *	Fla. sand †	Crushed quartz	Snow	Plaster of paris	White paper	Sodium ‡ carbonate	Sodium chloride	White cotton cloth §
0.3 to 0.4μ	8	15	40	35	40	8	14	38	26
0.4 to 0.8μ	25	40	50	40	53	30	28	49	42
0.8 to 2.6μ	33	50	53	15	60	30	35	54	40
2.6 to 7μ	31	30	28	18	63	15	18	55	20
7μ	48	..	..	26	..	..	..	..	..

* Yellow white grains of many kinds. † Very white. ‡ Anhydrous. § Handkerchief.

TABLE 432.—Reflecting Power of Powders (White Light)

Various pure chemicals, very finely powdered and surface formed by pressing down with glass plate. White (noon sunlight) light. Reflection in per cent. Nutting, Jones, Elliott, Tr. Ill. Eng. Soc. 9, 593, 1914.

Aluminum oxide	83.6	Magnesium carbonate	86.6	Sodium chloride	78.1
Barium sulphate	81.1	" " (block)	97.5	Sodium sulphate	77.9
Borax	81.6	Magnesium oxide	85.7	Starch	80.3
Boric acid	83.2	Rochelle salt	79.3	Sugar	87.8
Calcium carbonate	83.8	Salicylic acid	81.1	Tartaric acid	79.1
Citric acid	81.5	Sodium carbonate	81.8		

TABLE 433.—Variation of Reflecting Power of Surfaces with Angle

Illumination at normal incidence, 1¼ watt tungsten lamp, reflection at angles indicated with normal. Ill. Eng. Soc., Glare Committee, Tr. Ill. Eng. Soc. 11, p. 92, 1916.

Angle of observation.	0°	1°	3°	5°	10°	15°	30°	45°	60°
Magnesium carbonate block	0.88	—	—	0.88	0.88	0.87	0.83	0.72	0.68
Magnesium oxide	0.80	—	—	0.80	0.80	0.80	0.77	0.75	0.66
Matt photographic paper	0.78	—	—	0.78	0.78	0.78	0.78	0.76	0.72
White blotter	0.76	—	—	0.76	0.76	0.76	0.73	0.70	0.67
Pot opal, ground	0.69	0.69	0.69	0.69	0.69	0.69	0.68	0.66	0.64
Flashed opal, not ground	11.3	11.3	11.3	0.31	0.22	0.21	0.20	0.20	0.18
Glass, fine ground	0.29	0.29	0.29	0.29	0.27	0.20	0.14	0.13	0.12
Glass, course ground	0.23	0.22	0.21	0.20	0.19	0.16	0.11	0.11	0.12
Matt varnish on foil	0.83	—	0.78	0.72	0.62	0.49	0.28	0.21	0.16
Mirror with ground face	4.9	—	—	4.55	3.86	3.03	0.78	0.42	0.35

The following figures, taken from Fowle, Smithsonian Misc. Col. 58, No. 8, indicate the amount of energy scattered on each side of the directly reflected beam from a silvered mirror; the energy at the center of the reflected beam was taken as 100,000, and the angle of incidence was about 3°.

Angle of reflection, 3° ±	0′	8′	10′	15′	20′	30′	45′	60′	100′
Energy	100,000	600	244	146	107	66	33	22	11

Wave-length of max. energy of Nernst lamp used as source about 2μ.

TABLE 434

THE REFLECTING POWER OF BUILDING MATERIALS

Filter I (1.78μ), Chance's blue-green contrast filter No. 6, 3.3 mm thick, with their orange contrast filter No. 4, 2.7 mm thick. Filter II (0.84μ), 2 cm water-cell, Chance's orange contrast filter No. 4, and cobalt-blue glass, 1.8 mm thick. Filter III (0.61μ), 1 cm $K_2Cr_2O_7$ sol. (72 g/l) and 1 cm cell $CuSO_4$ sol. (57 g of hydrated salt/l). Filter IV (0.50μ), 2 cm cell $CuSO_4$ sol. sat. at 14.2° C. Gold film: radiation from "pointalight" through a thin gold film can be used in place of sunlight (compare with computed values). (Beckett, Proc. Phys. Soc., 43, 227, 1931.)

Description	I (1.78μ)	II (0.84μ)	III (0.61μ)	IV (0.50μ)	Gold film	Computed
Magnesium carbonate	0.63	0.99	0.98	0.96	0.96	....
CLAY TILES						
Dutch: light red	0.68	0.66	0.56	0.21	0.57	0.52
Machine-made: red	.72	.42	.34	.11	.38	.38
" red	.55	.38	.31	.11	.34	.33
" lighter red	.52	.40	.32	.13	.34	.33
" dark purple	.22	.22	.19	.13	.19	.18
Hand-made: red	.60	.47	.37	.12	.40	.39
" red-brown	.55	.33	.28	.13	.31	.31
CONCRETE TILES						
Uncolored	0.37	0.38	0.36	0.27	0.35	0.33
Brown	.13	.17	.15	.09	.15	.13
Brown: very rough	.08	.13	.13	.10	.12	.11
Black	.06	.09	.09	.09	.09	.08
SLATES						
Dark gray: smooth	0.09	0.11	0.11	0.11	0.11	0.10
" fairly rough	.10	.11	.10	.09	.10	.10
" rough	.09	.10	.11	.11	.10	.10
Greenish gray: rough	.16	.11	.12	.13	.12	.13
Mauve	.14	.16	.13	.10	.14	.13
Blue-gray	.20	.16	.13	.12	.13	.15
Silver-gray (Norwegian)	.22	.21	.21	.19	.21	.20
OTHER ROOFING MATERIALS						
Asbestos cement: white	0.35	0.42	0.41	0.36	0.41	0.39
" red	.33	.33	.29	.14	.31	.26
Enamelled steel: white	.35	.53	.53	.57	.52	.52
" green	.26	.34	.17	.13	.24	.25
" red	.24	.26	.18	.08	.19	.19
" blue	.23	.27	.17	.18	.20	.23
Galvanized iron: new	.58	.30	.34	.34	.35	.35
" very dirty	.10	.09	.09	.09	.09	.09
" whitewashed	.63	.79	.79	.76	.78	.74
Special roofing sheet: brown	.20	.15	.12	.07	.13	.13
" green	.13	.20	.12	.12	.14	.15
Bituminous felt	.10	.12	.11	.11	.12	.11
Aluminized felt	.67	.60	.61	.57	.62	.60
Weathered asphalt	.12	.12	.11	.09	.11	.11
Roofing lead: old	.46	.20	.19	.15	.21	.23
BRICKS						
Gault: cream	0.74	0.69	0.64	0.43	0.64	0.61
Stock: light fawn	.56	.47	.38	.19	.44	.39
Fletton: light portion	.67	.61	.57	.35	.58	.52
" dark portion	.54	.46	.37	.15	.41	.37
Wire cut: red	.56	.48	.41	.15	.44	.39
Sand-lime: red	.41	.37	.30	.11	.32	.30
Mottled purple	.33	.26	.22	.15	.23	.23
Stafford: blue	.21	.12	.11	.08	.11	.12
Lime-clay (French)	.57	.63	.52	.29	.54	.49

For classification of various light and radiation filters with bibliography, plots, and discussions, see Gibson, Spectral Filters, Journ. Opt. Soc. Amer., 13, 267-280, 1926.

Filters for the reproduction of sunlight and daylight and the determination of color temperatures, see Davis, Gibson, Bur. Standards Misc. Publ. 114, 1931.

TABLE 435.—Light Filters, Narrow Spectrum Regions

(Jones, Journ. Opt. Soc. Amer., 16, 259, 1928. Filters from the following components: Distilled H_2O; Aq. sol. $CuSO_4 \cdot 5H_2O$; $NiSO_4 \cdot 7H_2O$; Glasses, Corning G 986A, G 586, G 980A; dyed gelatin, Wratten filters 88A, 25, 61, 49.)

Filter and Absorbent	Concentration thickness	Wave lengths limits	Max.	Transmission at max.
88A	....	.720– 1.400	...	.80
88A, H_2O	2 cm	.720– 1.380	.800	.72
88A, G 986A	.32 cm	.720– 1.020	.770	.35
25, $CuSO_4 \cdot 5H_2O$	5%, 2 cm	.590– .690	.630	.26
61, "	5%, 2 cm	.490– .690	.530	.52
49, "	5%, 2 cm	.380– .500	.460	.26
G 586, "	.32 cm; 10%, 2 cm	.330– .430	.380	.69
G 986, $NiSO_4 \cdot 7H_2O$	.32 cm; 50%, 1 cm	.260– .360	.310	.50

TABLE 436.—Absorbing Power of Various Materials—Infra-red.

(Cartwright, Phys. Rev., 35, 415, 1930.)

The absorptive power is an integrated effect over the entire far infra-red. Litharge, powdered glass, white lead, copper sulphide, celestite, and red phosphorus were the best absorbers beyond 50μ. A very thin coat of the absorbing material in most cases was an inefficient absorber of the extreme infra-red waves. A very poor absorbing material in most cases such as copper or platinum will absorb if the surface is sufficiently rough.

For radiometers, the absorbing material is better when mixed with turpentine and alcohol and painted on the vanes. For thermocouples, the absorbing material is better if it is mixed with lacquer. 60-fold sensitiveness and better steadiness comes from evacuation.

The high absorption of glass in the near infra-red suggests its use as a source of radiation. Two Pt wires separated by 4 mm and covered with glass were heated by an electric current; the hot portion of the glass between the wires served as a source of extreme infra-red radiation. A convenient method of filtering out the near infra-red is to grind the windows with emery so that the pits are about 4μ deep. The apparatus may be adjusted with visible light by covering the rough surface with turpentine.

Substance	Radiation absorbed for $\lambda < 5\mu$ V	$\lambda > 50\mu$ I	I/V
Litharge	10.8	4.3	.40
Ground glass	11.9	4.7	.40
Powdered glass	11.7	5.0	.43
White lead 2 Pb $CO_3 \cdot Pb(OH)_2$	14.9	4.9	.33
White lead in lacquer	14.3	4.4	.31
Red phosphorus	18.3	5.0	.27
Red phosphorus from a match box	17.7	5.1	.29
Celestite, powdered $SrSO_4$	14.7	4.6	.31
Brucite, powdered $Mg(OH)_2$	11.4	4.2	.37
Angelsite, powdered $PbSO_4$	14.2	4.2	.30
Copper sulphide	17.1	5.2	.30
Copper oxide	13.8	4.4	.32
Silver sulphide	12.8	4.4	.34
Copper sulphate crystals from solution	15.0	4.1	.27
Wellsbach mantle material	8.9	3.1	.35
Platinum black	18.2	4.4	.24
Tartaric acid and sugar	16.0	3.9	.24
Talc	12.5	3.8	.30
Water glass	12.1	3.7	.31
Tellurium, powdered	19.2	3.3	.17
India ink	18.8	3.8	.20
Lacquer	8.6	3.0	.35
Castor oil	8.8	2.8	.32
Glycerine	11.2	3.1	.28
Turpentine	8.1	0.2	.02
Clean receiver	2.9	0.2	.07

Table 437

TRANSMISSIBILITY OF RADIATION BY DYES

Percentage transmissions of aqueous solutions taken from The Physical Basis of Color-Technology, Luckiesh, J. Franklin Inst. 184, 1917.

Spectrum color →	Violet.	Blue.		Green.			Yellow.		Orange.			Red.		
Wave-length in μ →	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68	.70
Carmen ruby opt.	—	—	—	—	—	—	—	—	—	4	18	37	49	60
Amido naphthol red	—	—	—	—	—	—	—	—	4	38	75	92	96	96
Coccinine	—	—	—	—	—	—	—	4	56	96	98	98	98	98
Erythrosine	6	—	—	—	—	—	1	53	90	95	96	96	96	96
Hematoxyline	1	3	7	13	14	12	13	25	44	54	63	73	78	82
Alizarinered	1	1	2	3	4	6	11	22	39	54	65	72	77	79
Acid rosolic (pure)	4	3	1	—	—	—	2	38	78	88	90	91	92	92
Rapid filter red	—	—	—	—	—	1	10	47	86	95	96	96	96	96
Aniline red fast extra A	—	—	—	—	—	2	12	34	55	72	84	88	90	92
Pinatype red fast	—	—	—	—	—	—	—	—	11	35	55	65	68	69
Eosine	—	—	—	—	—	—	1	54	87	93	92	92	92	92
Rose bengal	80	70	34	6	1	—	14	82	96	97	98	98	98	98
Cobalt nitrate	69	51	40	31	32	48	67	82	87	90	90	90	90	90
Tartrazine	—	—	—	—	7	52	75	86	91	95	96	97	98	98
Chrysoidin	—	—	—	—	—	—	—	—	2	23	50	71	70	79
Aurantia	—	—	—	—	—	3	23	53	82	92	96	96	96	96
Aniline yellow phosphine	—	—	—	—	2	20	43	60	67	75	81	85	86	87
Fluorescein	15	1	—	—	48	91	97	98	98	98	98	98	98	98
Aniline yellow fast S	—	—	1	7	43	84	96	96	96	96	96	96	96	96
Methyl orange indicator	—	—	—	—	—	—	1	31	70	79	80	81	81	81
Uranine	15	1	—	1	58	96	97	97	97	97	97	97	97	97
Uranine naphthaline	—	—	—	4	53	77	82	83	84	85	86	86	87	87
Orange B naphthol	—	—	—	—	—	1	43	88	95	96	97	97	97	97
Safranine	—	—	—	—	—	—	—	—	3	27	64	85	93	93
Martius gelb	—	—	—	1	43	84	91	94	95	95	95	95	95	95
Naphthol yellow	—	—	1	18	74	91	96	97	98	98	98	98	98	98
Potassium bichromate, sat.	—	—	—	—	—	10	60	84	88	89	89	89	89	88
Cobalt chromate	17	36	62	82	88	90	92	93	95	96	96	96	96	95
Naphthol green	2	4	7	21	30	36	29	16	7	2	1	—	—	—
Brilliant green	4	39	69	52	23	4	—	—	—	—	—	2	23	64
Filter blue green	35	49	64	70	60	37	13	2	—	—	—	—	—	—
Malachite green	—	12	20	8	1	—	—	—	—	—	—	—	12	50
Saurgrün	3	29	57	57	39	19	4	1	—	—	—	—	4	30
Methylengrün	28	31	32	26	17	7	2	1	—	—	—	—	3	28
Aniline green naphthol B	2	6	14	24	34	40	32	14	4	1	—	—	—	—
Neptune green	—	40	63	41	13	1	—	—	—	—	—	—	—	5
Cupric chloride	77	84	89	92	92	89	80	67	52	36	19	6	2	—
Turnbull's blue	58	60	56	51	38	28	18	9	5	3	1	—	—	—
Victoria blau	52	23	9	1	—	—	—	—	—	1	4	21	49	73
Prussian blue (soluble)	66	71	76	69	60	46	32	20	12	7	5	3	3	—
Wasser blau	89	75	51	26	7	1	—	—	1	2	6	18	37	60
Resorcine blue	25	18	6	2	1	—	—	—	1	2	14	41	64	72
Toluidin blau	66	31	13	3	1	—	—	—	—	—	1	4	16	40
Patent blue	83	91	84	76	65	46	24	8	2	—	—	6	42	78
Dianil blue	77	69	59	48	35	24	15	9	5	5	7	14	29	53
Filter blue	84	79	66	44	27	17	14	19	36	56	74	81	88	92
Aniline blue, methyl	92	88	78	52	27	9	3	2	2	4	8	16	25	45
Magenta	21	8	2	1	—	—	1	22	73	93	97	97	97	97
Gentiana violet	89	83	64	44	26	19	15	10	13	42	75	92	93	94
Rosazeine	50	28	2	—	—	—	—	6	55	90	98	98	98	98
Iodine (dense)	—	—	—	—	—	—	—	—	—	—	1	93	11	23
Rhodamine B	81	71	45	13	2	—	—	23	83	96	96	96	95	94
Acid violet	84	76	68	50	33	26	27	34	49	70	84	96	96	96
Cyonine in alcohol	7	1	—	—	—	—	—	—	—	—	—	1	13	23
Xylene red	39	23	1	—	—	—	—	1	27	79	97	97	97	96
Methyl violet B	25	4	—	—	—	—	—	—	—	—	3	26	63	89

For the infra-red transmission (to 12μ) and reflection powers of a number of aniline dyes, see Johnson and Spence, Phys. Rev. 5, p. 349, 1915.

Scientific Paper 440 of the Bureau of Standards, 1922, gives spectrum transmission curves (0.24 to 1.36 μ) for the following dyes. Napthol Yellow S, Orange I, Amaranth, Erythrosine, Indigo Disulpho Acid, Ponceau 3R, and Light Green S F Yellowish.

TABLE 438.—Transmissibility of Radiation by Jena Glasses

Coefficients, a, in the formula $I_t = I_0 a^t$, where I_0 is the Intensity before, and I_t after, transmission through the thickness t. Deduced from observations by Müller, Vogel, and Rubens as quoted in Hovestadt's Jena Glass (English translation).

Unit t = 1 dm.	Coefficient of transmission, a.									
	.375 μ	.390 μ	.400 μ	.434 μ	.436 μ	.455 μ	.477 μ	.503 μ	.580 μ	.677 μ
O 340, Ord. light flint	.388	.456	.614	.569	.680	.834	.880	.880	.878	.939
O 102, **H'vy** silicate flint	–	.025	.463	.502	.566	.663	.700	.782	.828	.794
O 93, Ord. " "	–	–	–	–	.714	.807	.899	.871	.903	.943
O 203, " " crown	.583	.583	.695	.667	.806	.822	.860	.872	.872	.903
O 598, (Crown)	–	–	–	–	.797	.770	.771	.776	.818	.860

Unit t = 1 cm.	0.7 μ	0.95 μ	1.1 μ	1.4 μ	1.7 μ	2.0 μ	2.3 μ	2.5 μ	2.7 μ	2.9 μ	3.1 μ
S 204, Borate crown	1.00	.99	.94	.90	.85	.81	.69	.43	.29	.18	–
S 179, Med. phosp. cr.	–	.98	.95	.90	.84	.67	.49	.87	.18	–	–
O 1143, Dense, bor. sil. cr.	.98	–	.97	–	.95	.93	.90	.84	.71	.47	.27
O 1092, Crown	.99	.96	.95	.99	.99	.91	.82	.71	60	.48	.29
O 1151, "	.98	–	.99	.99	.98	.94	.90	.79	.75	.45	.32
O 451, Light flint	1.00	–	.99	–	.98	.95	.92	.84	.78	.54	.34
O 469, Heavy "	1.00	–	.98	–	.99	.98	.98	.97	.90	.66	.50
O 500, " "	1.00	–	1.00	–	1.00	–	1.00	.99	.92	.74	.53
S 163, " "	1.00	–	.98	–	.99	–	.99	–	.94	.78	.60

TABLE 439.—Transmissibility of Radiation by Jena Colored Glasses

Taken from Catalog 4213, 1931, Schott and Gen, (41 glasses). R is reflection factor yellow light for two surfaces. Values of transmission are for 1 mm thickness. Ordinary figures refer to wave lengths in μ, .281 to .775, black-faced to infra-red.

Glass durability	Density R	.281 **.850**	.302 **.950**	.334 **1.15**	.366 **1.30**	.436 **1.60**	.480 **2.00**	.546 **2.20**	.578 **2.40**	.644 **2.60**	.700 **2.80**	.775 **3.00**
U G 1	2.77	.00	.17	.69	.85	.00	.00	.00	.00	.00	.01	.34
⅔	**.911**	**.22**	**.11**	**.05**	**.04**	**.03**	**.04**	**.06**	**.11**	**.15**	**.19**	**.17**
B G 1	2.50	.04	.40	.93	.97	.86	.44	.04	.05	.01	.51	.94
3	**.915**	**.97**	**.93**	**.76**	**.58**	**.40**	**.50**	**.59**	**.69**	**.74**	**.75**	**.55**
B G 4	2.41	.00	.00	.04	.74	.87	.53	.01	.01	.00	.07	.13
5	**.921**	**.12**	**.11**	**.13**	**.12**	**.14**	**.21**	**.45**	**.59**	**.63**	**.45**	**.40**
B G 10	2.60	.00	.00	.14	.64	.93	.95	.94	.88	.75	.62	.42
½	**.916**	**.31**	**.25**	**.26**	**.31**	**.47**	**.55**	**.56**	**.58**	**.55**	**.47**	**.46**
V G 1	2.93	.00	.00	.00	.00	.02	.47	.77	.56	.12	.06	.04
2	**.905**	**.05**	**.09**	**.18**	**.27**	**.47**	**.65**	**.71**	**.76**	**.77**	**.69**	**.55**
G G 2	2.58	.00	.00	.00	.64	.99	1.00	1.00	1.00	1.00	1.00	1.00
3	**.916**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**.99**	**.99**	**.98**	**.94**	**.84**	**.70**
G G 4	2.73	.00	.00	.03	.01	.67	.92	.97	.96	.94	.96	.99
2	**.913**	**.99**	**.99**	**.99**	**.99**	**.99**	**.99**	**.99**	**.98**	**.94**	**.85**	**.64**
G G 11	2.54	.00	.00	.00	.00	.01	.24	.99	.99	.99	.99	.98
2	**.913**	**.97**	**.96**	**.96**	**.99**	**.96**	**.97**	**.97**	**.95**	**.91**	**.82**	**.66**
R G 2	2.74	.00	.00	.00	.00	.00	.00	.00	.00	.92	.98	.98
2	**.913**	**.98**	**.98**	**.98**	**.98**	**.98**	**.98**	**.97**	**.95**	**.92**	**.81**	**.65**
R G 5	2.74	.00	.00	.00	.00	.00	.00	.00	.00	.02	.96	.98
2	**.913**	**.98**	**.98**	**.99**	**.99**	**.99**	**.99**	**.98**	**.97**	**.92**	**.79**	**.58**
N G 5	2.42	.00	.00	.00	.29	.59	.63	.66	.68	.70	.70	.65
1	**.919**	**.61**	**.59**	**.61**	**.65**	**.73**	**.78**	**.78**	**.76**	**.69**	**.58**	**.40**

U G 1 dark purple (u. v., extreme red). B G 1 blue (u. v., extreme red). B G 4 blue (i. r.). B G 10, light blue green, i. r. absorption. V G 1 yellow-green. G G 2 colorless, u. v. absorption. G G 4 almost colorless, strong u. v. absorption. G G 11 dark yellow for contrast filters. R G 2 pure red. R G 5 dark red. N G 5 light neutral.

TABLE 440.—Transmissibility of Radiation by Jena Ultra-violet Glasses

No. and Type of Glass.	Thickness.	0.397 μ	0.383 μ	0.361 μ	0.346 μ	0.325 μ	0.309 μ	0.280 μ
UV 3199 Ultra-violet	1 mm	1.00	1.00	1.00	1.00	1.00	0.95	0.56
" "	2 mm	0.99	0.99	0.99	0.97	0.90	0.57	
" "	1 dm	0.95	0.95	0.89	0.70	0.36		
UV 3248 "	1 mm	1.00	1.00	1.00	1.00	0.98	0.91	0.35
" "	2 mm	0.98	0.98	0.98	0.92	0.78	0.38	
" "	1 dm	0.96	0.87	0.79	0.45	0.08		

TABLE 441.—Transmissibility of Radiation by American Glasses

The following data giving the percentage transmission are selected from Coblentz, Emerson and Long, Bull. Bureau Standards, 14, 653, 1918.

Glass or substance, manufacturer	Thickness, mm.	Wave lengths in μ									
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Purple fluorite	4.98	—	—	—	47	48	48	57	60	62	62
Gold film on Crookes' glass	—	22	3	2	1	1	1	0	0	0	0
" " " crown glass	—	34	8	3	2	1	1	0	0	0	0
Molybdenite	.007	0	41	43	44	46	46	47	48	48	48
$Cr_2(SO_4)_3 \cdot 18\ H_2O$	.24	0	83	63	37	11	0	0	0	0	0
Chrome alum, 10 g to 100 g H_2O	10	—	73	0	0	—	—	—	—	—	—
$CoCl_2$, 10 g to 100 g H_2O	10	—	50	0	0	—	—	—	—	—	—
GLASSES:											
Copper ruby, flashed	1.95	—	50	64	72	76	40	33	36	7	0
G24, Corning, red, No. 243	5.90	—	60	70	72	65	2	1	0	0	0
Schott's red, No. 2745	3.18	—	83	89	89	75	10	10	0	0	0
G34, Corning, orange, No. 349	3.55	—	50	62	67	68	15	3	1	0	0
Pyrex, Corning, No. 774	1.55	90	90	90	91	87	35	13	7	2	0
Noviol, B, Corning, yellow	2.88	80	75	60	82	75	23	4	4	0	0
Novieweld 3, Corning, dark-yellow	2.2	12	1	2	6	13	6	7	7	1	0
Schott's 43111, green	3.43	50	4	53	79	83	25	9	0	0	0
G1710N, green, Corning	5.11	—	1	23	53	68	20	9	8	0	0
G174J, Corning, heat absorbing	2.6	—	2	4	12	19	11	4	6	0	0
G124JA, Corning	1.5	52	0	1	5	10	3	5	6	0	0
Cobalt blue	2.43	—	74	43	63	79	36	27	28	0	0
Schott's F3086, blue	2.58	—	0	1	2	31	11	5	4	0	0
G4013, Corning, blue	6.36	—	0	15	50	61	11	1	2	0	0
G584, Corning, blue, blue-green, No. 428	3.70	—	0	24	60	75	45	20	20	1	0
G1711Z, Corning, pale-blue-green	3.23	—	23	60	74	78	45	13	12	1	0
Amethyst, G172BW5, Corning	2.11	55	91	91	91	88	42	20	25	7	0
G172BW5, Corning, red-purple	4.43	—	0	0	2	5	6	8	12	2	0
Crookes' A, A. O. Co.	1.96	90	92	91	90	83	38	23	27	5	0
Crookes' sage green 30, A. O. Co.	1.98	50	0	0	4	11	8	8	11	3	0
Lab. 58, A. O. Co.	2.04	72	86	91	91	89	51	35	38	7	0
Fieurzal B, A. O. Co.	2.04	59	76	80	82	81	30	20	25	2	0
Akopos green, J. K. O. Co.	1.58	76	91	91	91	90	70	52	51	10	0

Manufacturers: Corning Glass Works, Corning, N. Y.; A. O. Co., American Optical Co., Southbridge, Mass.; J. K. O. Co., Julius King Optical Co., New York City. For other glasses see original reference. See also succeeding table, which contains data for many of the same glasses. For Corning Filters: Journ. Opt. Soc. Amer. 17, 40, 1928; Coblentz, Stair, Bur. Standards, Tech. Pap. 369, 1928; Sci. Pap., 113, 1929. Corning, Heat Transmitting, no. 254, 1 mm. transmits over 30%, 0.8 to 4μ; Sextant red, 2 mm. over 30% 0.8 to 4.2μ; Red Corex A, G986A, 3 mm., U. V. freely, visible to 0.4μ, i.r. with max. at 0.7 and 2.6μ.

TABLE 442.—Transmission of the Radiations from a Gas-filled Tungsten Lamp, the Sun, a Magnetite Arc, and from a Quartz Mercury Vapor Lamp (no Globe) through Various Substances, especially Colored Glasses.

Color.	Trade name.	Source.*	Thickness in mm	Transmission, per cent. Gas-filled tungsten.	Quartz mercury vapor.†	Magnetite arc.†	Solar radiation.
Greenish-yellow	Fieuzal, B	A. O. C.	2.04	71.6	26.9	46.0	63
" "	Fieuzal, 63	F. H. E.	1.80	75.5	34.3	55.0	72
" "	Fieuzal, 64	F. H. E.	1.65	50.7	22.0	—	—
" "	Euphos	B. S.	3.27	78.9	25.0	—	—
" "	Euphos, B	B. & L.	3.12	78.8	24.7	53.0	64
" "	Akopos green	J. K.	1.58	84.6	29.5	59.0	74
" "	Hallauer, 65	B. S.	2.36	70.3	17.7	—	—
" "	Hallauer, 64	F. H. E.	1.35	58.7	25.9	—	55
Smoky green	G 124, IP	C. G. W.	2.81	0.4	0.2	—	—
Yellow-green	Noviweld, 30%	C. G. W.	2.14	5.1	7.8	—	9
" "	Noviweld, shade 3	C. G. W.	2.20	3.4	4.2	2.7	—
" "	Noviweld, shade 4½	C. G. W.	2.20	1.6	1.2	0.8	—
" "	Noviweld, shade 6	C. G. W.	2.17	0.9	0.4	0.2	0.9
" "	Noviweld, shade 7	C. G. W.	2.17	0.8	0.2	—	—
Amber		B. S.	3.12	51.6	15.2	—	—
"	Saniweld, dark	J. K.	1.32	78.1	10.6	43.0	50
Orange	G 34	C. G. W.	3.57	56.9	17.0	—	47
Yellow	Noviol, shade A	C. G. W.	2.00	—	—	—	81
"	Noviol, shade B	C. G. W.	2.88	74.1	32.2	56.0	75
"	Noviol, shade C	C. G. W	2.00	—	—	—	72
Sage green	Ferrous No. 30	A. O. C.	1.95	5.3	17.5	—	17
Yellow-green	No. 61	A. O. C.	2.10	82.7	28.6	—	72
Blue-green	Lab. No. 59	A. O. C.	1.93	3.7	17.3	11.5	—
" "	G 124 JA	C. G. W.	1.53	5.3	21.5	12.5	19
Black	Smoke, C	B. & L.	2.26	65.3	31.2	52.0	60
"	Smoke, D	B. & L.	2.45	50.9	16.0	39.0	43
Neutral tint	Crookes, A	A. O. C.	1.97	85.3	46.1	—	89
" "	Crookes, B	A. O. C.	2.00	75.7	32.0	64.0	69
Gold plate	Pfund	A. O. C.	—	2.6	7.2	1.2	12
" " (darker)	Pfund	A. O. C.	—	—	1.3	—	—
Colorless	Lab. No. 58	A. O. C.	1.58	83.3	40.0	65	88
"	Lab. No. 57	A. O. C.	2.00	—	51.9	—	—
Amethyst	Shade C	A. O. C.	2.11	82.8	44.3	—	79
Purple	Electric smoke	A. O. C.	1.89	36.6	2.2	—	11
"	G 55 A 62	C. G. W.	2.85	17.4	17.0	—	16
Blue	Shade D	B. & L.	2.09	37.6	20.7	39	—
Blue, dark	G 53	C. G. W.	2.51	2.9	3.9	—	—
Blue-green	G 171-IZ	C. G. W.	3.21	46.6	41.7	—	—
Blue-green, pale	G 584	C. G. W.	3.75	24.9	25.2	—	—
Red-purple	G 172 BW 5	C. G. W.	4.93	72.4	26.5	—	—
Blue-purple	G 585	C. G. W.	3.13	35.8	34.0	—	41
Red	Selenium	C. G. W.	2.90	67.8	7.9	43	48
"		Schotts	3.22	69.4	—	—	46
"	Flashed	B. S.	—	—	4.8	—	—
Colorless	Window	B. S.	1.85	—	59.5	—	82
"	Crown	B. S.	1.56	—	64.9	—	92
Brown	Mica	B. S.	1.30	—	35.4	—	—
Colorless	Mica	B. S.	0.09	—	43.1	—	—
Clear	Water	B. S.	10.0	34.2	‡54.0	—	—

* A. O. C., Amer. Optical Co., Southbridge, Mass.; C. G. W., Corning Glass Works, Corning, N. Y.; B. & L., Bausch & Lomb, Rochester, N. Y.; J. K., Julius King Optical Co., New York City; F. H. E., F. H. Edmonds, optician, Washington, D. C.; B. S., Bureau of Standards; scrap material, source unknown.

† Infra-red radiation absorbed by quartz cell containing 1 cm layer of water. Taken from Coblentz-Emerson & Long, Bul. Bureau Standards, 14, 653, 1918.

‡ Transmission of 1 cm cell having glass windows.

TABLE 443.—Ultra-violet Transparency (302 $m\mu$)

Bur. Standards Res. Pap. no. 113, 3, 629, 1929, gives data for vitaglass, sunlit, helioglass uviol-Jena, neuglas, Corning Corex-D, quartz, celoglass, cellophane, tracing cloth. For various fabrics, see Res. Pap. no. 6. For depth of penetration of various wave lengths (u. v., i. r.) see Spectral Characteristics of Light Sources and Window Materials, Trans. Illum. Eng. Soc., 23, 251, 1928. Average per cent transmission of some glasses at 302 $m\mu$ when new and after 10 hr. exposure, distance 15 m, to 110 v tungsten u. v. quartz Hg lamp and sun 5 to 12 m. Qualities vary from sample to sample of glasses.

	Quartz glass	Corex-D	Neuglass	Uviol	Helio	Sunlit	Vitaglass
New	92	61	63	67	64	71	58
After lamp	92	59	50	48	45	41	33
After sun	92	60	57	53	53	51	42

TABLE 444(*a*).—Ultra-Violet Transparency Atmospheric Components

$I = I_0\,10^{-\alpha d}$, d in cm 0°C, 760 mm

Oxygen	
0.1900μ	α = 0.0014
.1920	.0007
.1929	.0022
.1947	.0007
.1950	.0021
.1955	.00075
.1962	.0020
.1970	.0007
.2000	.00043
.2050	.0003
.2100	.0002

Oxygen	
0.186μ	α = 0.0089
.193	.0015
O_2, air, Kreusler	
Air	
0.186μ	α = 0.0019
Water	
0.1875μ	α = 0.0055
.1900	.0026
.1950	.0012
.2000	.0007

Granath, Phys. Rev., 1929

Ozone	
0.2378μ	100.5
.2482	141
.2537	148.8
.2652	123
.2804	45.6
.2967	6.9
.3125	.96
.3341	.07

Lauchil, 1929

Ozone			
0.230μ	50	0.290μ	16.6
.240	95	.300	4.6
.250	120	.310	1.23
.260	120	.320	.35
.270	91	.330	.093
.280	46	.340	.024

Fabry, Buisson, 1913

Nitrogen
0.186 = 0.000478

Kreusler, 1901

Air at sea-level (Washington), 400 m practically no absorption λ > .3μ; < .28μ about that due to molecular scattering. Air transmission reduced by 1/100: 22 km at .28μ; 5 at 25μ; 0.57 at .22μ; 20 km at .205μ. (Dawson, Granath, Hulburt, Phys. Rev., 33, 1073, 1929.)

(*b*).—Atmospheric Transparency for Ultra-Violet

(Zenith sun, Fabry, Buisson, C. R. 175, 156, 1922; Astrophys. Journ., 54, 297, 1921; joined to Abbot's, Annals Astrophys. Obs. Smithsonian Inst., 2, 112, 1908, via Forsythe-Christison, Gen. Elec. Rev., 662, 1929.)

Wave length, μ......	.29	.30	.31	.32	.33	.34	.35	.37	.39	.41	.43	.45
% transmitted......	0	.9	9.	20.	27.	33.	38.	46.	51.	56.	60.	64.

TABLE 445.—Penetration Ultra-Violet Light into Sea Water

(Hulburt, 1928.)

The transparency of sea water declines rapidly with decreasing wave length (λ) in the u. v., becoming quite small below 3000 A. λ 3400 to 3000 A, $CaSO_4$ gives ½ the absorption, H_2O ¼; 3000 to 2500 A, $MgCl_2$, $CaSO_4$, H_2O each about ⅓. $I = I_0 10^{-ax}$, x in cm.

	mμ	254	266	280	303	313	366	436	546	578	612mμ
distilled water	a.....	.030	.021	.015	.005	.002	.001	.00005	.00015	.00028	.0010
tap water	".....	.045	.032	.020	.007	.003	.001	..	..	..	..
sea water	".....	.067	.057	.039	.017	.009	.0013	.00010	.00015	.0003	.0010

TABLE 446

TRANSPARENCY OF THE VARIOUS SUBSTANCES OF TABLES 394 TO 402

Alum: Ordinary alum (crystal) absorbs the infra-red.
Metallic reflection at 9.05μ and 30 to 40μ.

Rock-salt: Rubens and Trowbridge (Wied. Ann. 65, 1898) give the following transparencies for a 1 cm. thick plate in %:

λ	9	10	12	13	14	15	16	17	18	19	20.7	23.7μ
%	99.5	99.5	99.3	97.6	93.1	84.6	66.1	51.6	27.5	9.6	0.6	0.

Pflüger (Phys. Zt. 5. 1904) gives the following for the ultra-violet, same thickness: 280$\mu\mu$, 95.5%; 231, 86%; 210, 77%; 186, 70%.
Metallic reflection at 0.110μ, 0.156, 51.2, and 87μ.

Sylvite: Transparency of a 1 cm. thick plate (Trowbridge, Wied. Ann. 60, 1897).

λ	9	10	11	12	13	14	15	16	17	18	19	20.7	23.7μ
%	100.	98.8	99.0	99.5	99.5	97.5	95.4	93.6	92.	86.	76.	58.	15.

Metallic reflection at 0.114μ, 0.161, 61.1, 100.

Fluorite: Very transparent for the ultra-violet nearly to 0.1μ.
Rubens and Trowbridge give the following for a 1 cm. plate (Wied. Ann. 60, 1897):

λ	8μ	9	10	11	12μ
%	84.4	54.3	16.4	1.0	0

Metallic reflection at 24μ, 31.6, 40μ.

Iceland Spar: Merritt (Wied. Ann. 55, 1895) gives the following values of k in the formula $i = i_0 e^{-kd}$ (d in cm.):
For the ordinary ray:

λ	1.02	1.45	1.72	2.07	2.11	2.30	2.44	2.53	2.60	2.65	2.74μ
k	0.0	0.0	0.03	0.13	0.74	1.92	3.00	1.92	1.21	1.74	2.36

λ	2.83	2.90	2.95	3.04	3.30	3.47	3.62	3.80	3.98	4.35	4.52	4.83μ
k	1.32	0.70	1.80	4.71	22.7	19.4	9.6	18.6	∞	6.6	14.3	6.1

For the extraordinary ray:

λ	2.49	2.87	3.00	3.28	3.38	3.59	3.76	3.90	4.02	4.41	4.67μ
k	0.14	0.08	0.43	1.32	0.89	1.79	2.04	1.17	0.89	1.07	2.40

λ	4.91	5.04	5.34	5.50μ
k	1.25	2.13	4.41	12.8

Quartz: Very transparent to the ultra-violet; Pflüger gets the following transmission values for a plate 1 cm. thick: at 0.222μ, 94.2%; 0.214, 92; 0.203, 83.6; 0.186, 67.2%.
Merritt (Wied. Ann. 55, 1895) gives the following values for k (see formula under Iceland Spar):
For the ordinary ray:

λ	2.72	2.83	2.95	3.07	3.17	3.38	3.67	3.82	3.96	4.12	4.50μ
k	0.20	0.47	0.57	0.31	0.20	0.15	1.26	1.61	2.04	3.41	7.30

For the extraordinary ray:

λ	2.74	2.89	3.00	3.08	3.26	3.43	3.52	3.59	3.64	3.74	3.91	4.19	4.36μ
k	0.0	0.11	0.33	0.26	0.11	0.51	0.76	1.88	1.83	1.62	2.22	3.35	8.0

For $\lambda > 7\ \mu$, becomes opaque, metallic reflection at 8.50μ, 9.02, 20.75–24.4μ, then transparent again.

The above are taken from Kayser's "Handbuch der Spectroscopie," vol. iii.

TABLE 447.—Color Screens

The following light-filters are quoted from Landolt's "Das optische Drehungsvermögen, etc." 1898 Although only the potassium salt does not keep well it is perhaps safer to use freshly prepared solutions.

Color.	Thickness. mm.	Water solutions of	Grammes of substance in 100 c.cm.	Optical centre of band. μ	Transmission.
Red	20	Crystal-violet, 5BO	0.005	0.6659	begins about 0.718μ. ends sharp at 0.639μ.
"	20	Potassium monochromate	10.		
Yellow	20	Nickel-sulphate, $NiSO_4.7aq$.	30.	0.5919	0.614–0.574μ.
"	15	Potassium monochromate	10.		
"	15	Potassium permanganate	0.025		
Green	20	Copper chloride, $CuCl_2.2aq$.	60.	0.5330	0.540–0.505μ
"	20	Potassium monochromate	10.		
Bright blue	20	Double-green, SF	0.02	0.4885	0.526–0.494 and 0.494–0.458μ
	20	Copper-sulphate, $CuSO_4.5aq$.	15.		
Dark blue	20	Crystal-violet, 5BO	0.005	0.4482	0.478–0.410μ
	20	Copper sulphate, $CuSO_4.5aq$.	15.		

TABLE 448.—Color Screens

The following list is condensed from Wood's Physical Optics :

Methyl violet, 4R' (Berlin Anilin Fabrik) very dilute, and nitroso-dimethyl-aniline transmits 0.365μ. Methyl violet + chinin-sulphate (separate solutions), the violet solution made strong enough to blot out 0.4359μ, transmits 0.4047 and 0.4048, also faintly 0.3984.

Cobalt glass + aesculin solution transmits 0.4359μ.

Guinea green B extra (Berlin) + chinin sulphate transmits 0.4916μ.

Neptune green (Bayer, Elberfeld) + chrysoidine. Dilute the latter enough to just transmit 0.579c and 0.5461 ; then add the Neptune green until the yellow lines disappear.

Chrysoidine + eosine transmits 0.5790μ. The former should be dilute and the eosine added until the green line disappears.

Silver chemically deposited on a quartz plate is practically opaque except to the ultra-violet region 0.3160–0.3260 where 90% of the energy passes through. The film should be of such thickness that a window backed by a brilliantly lighted sky is barely visible.

In the following those marked with a * are transparent to a more or less degree to the ultra-violet

* Cobalt chloride : solution in water, — absorbs 0.50–.53μ; addition of $CaCl_2$ widens the band to 0.47–.50. It is exceedingly transparent to the ultra-violet down to 0.20. If dissolved in methyl alcohol + water, absorbs 0.50–.53 and everything below 0.35. In methyl alcohol alone 0.485–0.555 and below 0.40μ.

Copper chloride : in ethyl alcohol absorbs above 0.585 and below 0.535 ; in alcohol + 50% water, above 0.595 and below 0.37μ.

Neodymium salts are useful combined with other media, sharpening the edges of the absorption bands. In solution with bichromate of potash, transmits 0.535–.565 and above 0.60μ, the bands very sharp (a useful screen for photographing with a visually corrected objective).

Praseodymium salts : three strong bands at 0.482, .468, .444. In strong solutions they fuse into a sharp band at 0.435–.485μ. Absorption below 0.34.

Picric acid absorbs 0.36–.42μ, depending on the concentration.

Potassium chromate absorbs 0.40–.35, 0.30–.24, transmits 0.23μ.

* Potassium permanganate : absorbs 0.555–.50, transmits all the ultra-violet.

Chromium chloride : absorbs above 0.57, between 0.50 and .39, and below 0.33μ. These limits vary with the concentration.

Aesculin : absorbs below 0.363μ, very useful for removing the ultra-violet.

* Nitroso-dimethyl-aniline : very dilute aqueous solution absorbs 0.49–.37 and transmits all the ultra-violet.

Very dense cobalt glass + dense ruby glass or a strong potassium bichromate solution cuts off everything below 0.70 and transmits freely the red.

Iodine : saturated solution in CS_2 is opaque to the visible and transparent to the infra-red.

TABLE 449.—Transmission Percentages of Radiation Through Moist Air

The values of this table will be of use for finding the transmission of energy through air containing a known amount of water vapor. An approximate value for the transmission may be had if the amount of energy from the source between the wave lengths of the first column is multiplied by the corresponding transmission coefficients of the subsequent columns. The values for the wave lengths greater than 18μ are tentative and doubtful. Fowle, Water-vapor Transparency, Smithsonian Misc. Coll., 68, No. 8, 1917; Fowle, The Transparency of Aqueous Vapor, Astrophys. Journ. 42, 394, 1915.

Range of wave lengths.		Precipitable water in centimeters.												
μ	μ	.001	.003	.006	.01	.03	.06	.10	.25	.50	1.0	2.0	6.0	10.0
0.75 to	1.0	—	—	—	100	99	99	98	97	95	93	90	83	78
1.0	1.25	—	—	—	99	99	98	97	95	92	89	85	74	69
1.25	1.5	—	—	—	96	92	84	80	66	57	51	44	31	28
1.5	2.0	—	—	—	98	97	94	88	79	73	70	66	60	57
* 2	3	96	92	87	84	77	70	.64	—	—	—	—	—	—
3	4	95	88	84	78	72	66	63	—	—	—	—	—	—
* 4	5	92	83	76	71	65	60	53	—	—	—	—	—	—
5	6	95	82	75	68	56	51	47	35	—	—	—	—	—
6	7	85	54	50	31	24	8	4	3	2	0	0	0	0
7	8	94	84	76	68	57	46	35	16	10	2	0	0	0
8	9	100	100	100	99	98	96	94	65	—	—	—	—	—
† 9	10	100	100	100	100	100	100	100	100	100	100	100	—	—
† 10	11	100	100	100	100	100	100	100	100	100	100	100	—	—
11	12	100	100	100	100	100	99	98	96	95	93	—	—	—
12	13	100	100	100	100	99	99	97	86	82	—	—	—	—
* 13	14	100	100	100	99	97	94	90	80	60	—	—	—	—
* 14	15	—	—	96	93	80	75	50	15	0	0	0	0	0
* 15	16	—	—	—	—	70	55	40	0	0	0	0	0	0
16	17	—	—	—	—	—	50	20	0	0	0	0	0	0
17	18	—	—	—	—	—	25	10	0	0	0	0	0	0
18	∞	98	94	89	82	45	0	0	0	0	0	0	0	0

* These places require multiplication by the following factors to allow for losses in CO_2 gas. Under average sea-level outdoor conditions the CO_2 (partial pressure = 0.0003 atmos.) amounts to about 0.6 gram per cu. m. Paschen gives 3 times as much for indoor conditions.

2μ to 3μ, for 2 grams in m^2 path (95); for 140 grams in m^2 path (93);
4 " 5 " " " " " " " (93); " " " " " " (70); more CO_2 no further effect;
13 " 14, slight allowance to be made;
14 " 15, 80 grams in m^2 path reduces energy to zero;
15 " 16, " " " " " " " " "

† These places require multiplication by 0.90 and 0.70 respectively for one air mass and 0.85 and 0.65 for two air masses to allow for ozone absorption when the radiation comes from a celestial body.

TABLE 450.—Transparency of Water Vapor (steam)

(Hettner, Ann. Phys., 55, 476, 1918, places of greater absorption. Original article gives plot of absorption throughout range of wave lengths.)

Wave length	Steam	Absorption	Wave length	Steam	Absorption	Wave length	Steam	Absorption
0.95μ	109 cm	7%	6.5μ	32.4 cm	80%	20μ	32.4	80%
1.13	"	14	11	104	15	22	"	22
1.36	"	75	13	104	35	26	"	30
1.84	"	84	15	104	55	30	"	50
2.64	"	100	18	32.4	55	34	"	80

TABLE 451.—Transparency of Water

Values of a in $I = I_0 e^{ad}$, d in cm I_0, I, intensity before and after transmission.

Wave length μ,	.186	.193	.200	.210	.220	.230	.240	.260	.300	.415
a	.0688	.0165	.009	.0061	.0057	.0034	.0032	.0025	.0015	.00035
Wave length μ,	.430	.450	.487	.500	.550	.600	.650	.779	.865	.945
a	.00023	.0002	.0001	.0002	.0003	.0016	.0025	.272	.296	.538

First 9; Kreusler, Drud. Ann. 6, 1901; next Ewan, Proc. R. Soc. 57, 1894, Aschkinass, Wied Ann. 55, 1895; last 3, Nichols, Phys. Rev. 1, 1.
See Rubens, Ladenburg, Verh. D. Phys. Ges., p. 19, 1909, for extinction coefs, reflective power and index of refraction, 1 μ to 18 μ.

INFRA-RED TRANSMISSION AND ABSORPTION

TABLE 452.—Per Cent Transmission, Gases, 6.7 to 32.8μ

(Strong, Phys. Rev., 37, 1565, 1931, restrahlung.)
Length of cell, 4 inches.

Material	Pressure	6.7μ	8.7μ	20.75μ	22.9μ	27.3μ	29.4μ	32.8μ
NH_3	760 mm	24	26	79	93	83	82	62
C_2H_2	760	95	92	99	101	101	100	98
H_2S	760	97	98	98	97	92	90	83
SO_2	760	98	5	7	58	100	100	96
C_6H_6	96	65	97	102	99	100	98	95
CCl_4	114	95	99	97	99	99	99	91
CS_2	361	30	98	100	86	98	99	96
$CHCl_3$	200	93	90	99	98	98	97	97
$(C_2H_5)_2O$	526	17	6	61	45	69	71	61

TABLE 453.—Per Cent Transmission, Solids, 6.7 to 32.8μ

Material	Description	6.7μ	8.7μ	20.75μ	22.9μ	27.3μ	29.4μ	32.8μ
Lacquer film	±.55μ thickness	96	93	97	98	99	99	100
Mica	10μ thickness	83	22	19	00	35	42	44
Soot on lacquer	Opaque to visible	25	22	67	53	60	67	60
Quartz, fused	10μ thickness	86	02	01	03	51	55	68
Glass	3μ thickness	93	07	12	14	48	51	56
Cellophane	25μ thickness	33	04	04	01	20	25	26
MgO	Deposit from burning Mg ribbon	88	86	04	02	90	93	87
ZnO	Deposit from Zn arc	99	80	15	05	93	79	80

TABLE 454.—Per Cent Reflection, Solids, 22.9 and 32.8μ

Description of reflector	22.9μ	32.8μ
Deposit of MgO from burning Mg ribbon	0	0
Reflection β-MgO	80	33
Mica	32	..
Paraffin	04	..
Pencil mark on paper	09	..
Silver covered with Soot coating	43	48
Silver covered with MgO coating	08	91
Silver covered with ZnO coating	01	52
Silver covered with Optical black	31	..
Gold foil blackened with bismuth	>19	.
KBr + 1.5μ CaF_2 deposited by evaporation	10	..
KI + 1.5μ CaF_2 deposited by evaporation	13	..

TABLE 455.—Per Cent Transmission, Various Substances, 20 to 130μ

(Barnes, Phys. Rev., 39, 562, 1932, which see for special technique used for analysis in this region.)

		20μ	30	40	50	60	70	80	90	100	110	120	130μ
Fused quartz	0.2 mm	0	0	2	20	35	51	53	52	..	..	..	..
" "	1.0 "	0	0	0	0	0	0	5	6	18	30	22	27
Crystal " ‖	1.0 "	0	1	7	42	57	62	59	72	71	78	70	72
Sulphur, rhombic	0.9 "	30	40	10	6	39	37	52	58	51	56	58	38
Paraffin	2.0 "	19	35	42	51	58	64	65	75	85	79	76	70
Mica	6μ	6	18	50	53	46	57	50	21	27	50	(55)	(55)
Cellophane	40μ	0	16	22	23	24	24	23	23	29	30	30	42
Celluloid	1μ	92	93	95	96	96	97	97	98	98	99	99	99
Black paper	0.1 mm	..	..	..	2	5	13	19	22	23	26	28	30
Camphor soot	*	60	76	79	80	81	82	84	85	86	87	89	90
Pfund Bi black	*	30	40	44	48	50	40	45	58	60	57	60	63
Lampblack, water glass	0.8†	0	(1)	(3)	7	12	21	20	26	30	25	30	30

* On celluloid 1μ thick. † For Rubens, Hoffmann, lampblack-water-glass mixture see Berliner Ber. 424, 1922. For Pfund's Bi Black see Rev. Sci. Instr., 1, 397, 1930. A considerable number of bands appear in some of the curves from which the above values were read.

FAR INFRA-RED, 20 TO 150μ

(John Strong, Phys. Rev., 38, 1818, 1931.)

TABLE 456.—Restrahlung bands

Number of reflections	Crystal mirrors	Filter (3 mm paraffin in each case)	Wave length in μ	Frequency in ~/cm
4	Quartz	1 cm KCl	20.7	483
3	Fluorite	5 mm KCl	23	435
1	Metal			
2	Fluorite	3 mm KBr	27.3	366
4	Calcite		29.4	340
3	Fluorite	0.4 mm quartz	32.8	305
1	Metal	1.2 mm KBr		
3	Aragonite	0.4 mm quartz	41 * †	244
1	Metal			
4	NaCl	2 mm quartz	52	192
4	KCl	"	63	159
4	KBr	"	83	120
4	KI	"	94	106
4	TlBr	"	117	85
4	TlI	"	152	66

* The use of a paraffin window about 3 mm thick stops the short wave length restrahlung of quartz at 8.7μ and of calcite at 6.7μ.
† Weak reflection at 41μ.

TABLE 457.—Reflecting Power

	λ = 20μ ~/cm = 500	25 400	33⅓ 300	50 200	66⅔ 150	100 100	150μ 66⅔	
Rough brass	67	70	78	83	92	96	100	(1)
" "	24	33	42	58	68	81	99	(2)
" "	12	14	17	21	25	40	82	(3)
Galena	31	30	21	51	73	76	76	(4)
Zincite	50	35	18	21	18	20	15	(5)
β magnesia, fused......	80	60	34	30	30	30	30	...
Stibnite	21	20	4	39	48	52	39	(6)
Sphalerite	10	15	29	20	19	18	17	(6)
Corundum	(30)	41	26	31	29	24	22	(6)
Cuprite	45	47	47	42	41	42	46	...

(1) Ground with No. 60 carborundum. (2) Ditto No. 220. (3) Ditto No. 400. (4) Surface ‖ to cleavage plane, highly polished. (5) Natural crystal. (6) Qualitative only.

TABLE 458.—Transmission

	λ = 20μ ~/cm = 500	25 400	33⅓ 300	50 200	66⅔ 150	100 100	150μ 66⅔	
KBr	..	61	46	3	..	..	..	(7)
KI	..	83	76	12	..	..	..	(7)
Amorphous SiO_2	3	27	64	63	62	70	87	...
CCl_4 liquid	(57)	63	50	74	74	(72)	..	...
KCl	97	97	96	93	80	98	..	(8)

(7) No corrections for reflections. (8) Evaporated on lacquer film.

REFLECTION AND ABSORPTION OF LONG-WAVE RADIATIONS

TABLE 459.—Long-wave Absorption by Gases

Unless otherwise noted, gases were contained in a 20 cm long tube. Rubens, Wartenberg, Verh. d. Phys. Ges. 13, p. 796, 1911.

Gas.	Pressure, cm	Percentage absorption. 23μ	52μ	110μ	Long λ, Hg lamp.	Long λ, Hg lamp. Filtered, 314μ
H_2	76	100	100	100	100	100
Cl_2	76	100	99.6	99.5	98.5	97.6
Br_2	20	100	100	100	100	100
SO_2	76	22.6	76.9	12.7	6	4.8
CO_2	76	100	100	100	100	100
CO	76	100	100	94.1	92.1	91.6
H_2S	76	99.6	11.6	5.4	10.3	21.4
N_2O	76	100	96.8	98.4	93.3	90.8
NO	76	—	94	99	87.3	85.5
$(CN)_2$	76	100	97.8	100	99.3	—

Gas.	Pressure, cm	Percentage absorption. 23μ	52μ	110μ	Long λ, Hg lamp.	Long λ, Hg lamp. Filtered, 314μ
NH_3	76	83.1	0.5	99.2	43.3	66.7
CH_4	76	91	94.3	99.2	100	100
C_2H_2	76	99.5	87.4	97.3	97.9	100
C_2H_4	76	90	96.4	92.8	100	100
CS_2	26	97.8	100	100	99.5	100
C_2H_6O	6	85.4	5.4	58	52.4	49.9
$C_4H_{10}O$	51	20.8	40	34	21.8	10.7
C_5H_{12}	46	66 †	44.5	88.8	87	84.2
CH_3Cl	14	98	100	100	95.4	94.7
H_2O *	76	39.6	0.7	19.6	33.6	49.2

* Steam 100° C passed through tube 40 cm long, 150° C; 0.06 cm ppt. H_2O.
† Pentane vapor, pressure 36 cm.

TABLE 460.—Properties with Wave-lengths 108 ± μ

Rubens and Woods, Verh. d. Phys. Ges. 13, p. 88, 1911.
With quartz, 1.7 cm thick: 60 to 80μ, absorption very great; 63μ, 99%; 82μ, 97.5; 97μ, 83.

(a) PERCENTAGE REFLECTION.

Wave-length.	Iceland spar.	Marble.	Rock salt.	Sylvite	KBr	KI	Fluorite.	Glass.	Water.	Alcohol.
λ = 82μ *	—	—	25.8	36.0	82.6	29.6	19.7	—	9.6	—
λ = 108μ †	47.1	43.8	20.3	19.3	31.1	35.5	20.2	19.2	11.6	1.6

* Restrahlung from KBr. † Isolated with quartz lens.

(b) PERCENTAGE TRANSPARENCY.
Uncorrected for reflections.

Solid.	Thickness.	Transparency.	Liquid.	Thickness.	Thickness precipitable liquid.	Transparency.
Paraffin	3.03	57.0	Benzene	1.00	—	56.8
Mica	0.055	16.6	Ethyl alcohol	0.158	—	7.9
Hard rubber	0.40	39.0	Ethyl ether	0.158	—	37.1
Quartz ‖ axis	2.00	62.6	Water	0.029	—	25.8
Quartz, amorph.	3.85	0	Water	0.044	—	13.6
Rock salt	0.21	21.5				
Fluorite	0.59	5.3	Vapors:			
Diamond	1.26	45.3	Alcohol	2.00	0.023	88
Quartz ⊥ axis	2.00	81.3	Ether	2.00	0.350	33.5
" "	4.03	66.4	Benzene	2.00	0.063	100
" "	7.26	49.8	Water	4.00	0.21	19.6
" "	11.74	35.5	CO_2	2.00	—	100
" "	14.66	29.0				

(c) TRANSPARENCY OF BLACK ABSORBERS.

Method and wave-length.		Black silk paper, .025 mm thick.	Opaque black paper, 0.11 mm thick.	Black card-board, 0.4 mm thick.	Candle lamp-black, 10 cm² = 1.8 mg
Spectrometer	2μ	0	0	0	0.5
	4	0.9	0	0	8.6
	6	1.7	0	0	16.0
	12	8.2	1.4	0	37.6
Fluorite "reststrahlen"	26	24.2	3.2	0	76.7
Rock salt "reststrahlen"	52	46.0	15.1	0	91.3
Quartz lens isolation	108	61.5	33.5	1.6	91.5

ROTATION OF PLANE OF POLARIZED LIGHT

TABLE 461.—Tartaric Acid; Camphor; Santonin; Santonic Acid; Cane Sugar

A few examples are here given showing the effect of wave length on the rotation of the plane of polarization. The rotations are for a thickness of one decimeter of the solution. The examples are quoted from Landolt & Börnstein's "Phys. Chem. Tab." The following symbols are used:—

p = number grams of the active substance in 100 grams of the solution.
c = " " solvent " " " "
q = " " active " " cubic centimeter "

Right-handed rotation is marked +, left-handed −.

Line of spectrum	Wave length according to Angstrom in cm × 10⁶	Tartaric acid,* $C_4H_6O_6$, dissolved in water. q = 50 to 95, temp. = 24°C	Camphor,* $C_{10}H_{16}O$, dissolved in alcohol. q = 50 to 95, temp. = 22.9°C	Santonin,† $C_{15}H_{18}O_3$, dissolved in chloroform. q = 75 to 96.5, temp. = 20°C
B	68.67			−140°.1 + 0.2085 q
C	65.62	+2°.748 + 0.09446 q	38°.549 − 0.0852 q	−149.3 + .1555 q
D	58.92	+1.950 + .13030 q	51.045 − .0964 q	−202.7 + .3086 q
E	52.69	+ .153 + .17514 q	74.331 − .1343 q	−285.6 + .5820 q
b1	51.83	.. ..	.. ..	−302.38 + .6557 q
b2	51.72	− .832 + .10147 q	79.348 − .1451 q	.. ..
F	48.61	−3.598 + .23977 q	99.601 − .1912 q	−365.55 + .8284 q
e	43.83	−9.657 + .31437 q	149.696 − .2346 q	−534.98 + 1.5240 q

Line of spectrum	Wave length	Santonin,† $C_{15}H_{18}O_3$,* dissolved in alcohol. c = 1.782 temp. = 20°C	Santonin,† $C_{15}H_{18}O_3$ dissolved in alcohol. c = 4.046 temp. = 20°C	Santonin,† $C_{15}H_{18}O_3$ dissolved in chloroform. c = 3.1–30.5 temp. = 20°C	Santonic acid,† $C_{15}H_{20}O_4$, dissolved in chloroform. c = 27.192 temp. = 20°C	Cane sugar,‡ $C_{12}H_{22}O_{11}$, dissolved in water. p = 10 to 30
B	68.67	−110.4°	442°	484°	− 49°	See Supplementary table below
C	65.62	−118.8	504	549	− 57	
D	58.92	−161.0	693	754	− 74	
E	52.69	−222.6	991	1088	−105	
b1	51.83	−237.1	1053	1148	−112	
b2	51.72	—	—	—	—	
F	48.61	−261.7	1323	1444	−137	
e	43.83	−380.0	2011	2201	−197	
G	43.07	—	—	—	—	
g	42.26	—	2381	2610	−230	

* Arndtsen, Ann. Chim. Phys. (3) 54, 1858. † Narini, R. Acc. dei Lincei, (3) 13, 1882. ‡ Stefan, Sitzb. d. Wien. Akad. 52, 1865.

Supplementary to Table 461

Values obtained at the Bureau of Standards for the rotation of sucrose are given below.

Light Source	Rot. λ / Rot. λ = 5461	$[\alpha]^{20}_{\lambda}$	Light Source	Rot. λ / Rot. λ = 5461	$[\alpha]^{20}_{\lambda}$
Li 6708	.644	50.45	Cd 4678	1.403	109.9
Cd 6438	.711	55.70	Hg 4358	1.644	128.8
Na 5892.5	.84922	66.529	Ag 4208	1.786	139.9
Hg 5780	.8854	69.36	Hg 4047	1.95	152.8
Hg 5461	1.0000	78.342			
Ag 5209	1.108	86.80			
Cd 5086	1.167	91.43			
Cd 4800	1.323	103.65			

The above values are for a near normal solution, i.e. approximately 26 g of sucrose per 100 cc.

TABLE 462.—Sodium Chlorate; Quartz

Sodium chlorate (Guye, C. R. 108, 1889)				Quartz (Soret & Sarasin, Arch. de Gen. 1882, or C. R. 95, 1882)*					
Spectrum line	Wave length	Temp. C	Rotation per mm	Spectrum line	Wave length	Rotation per mm	Spectrum line	Wave length	Rotation per mm
a	7164A	15°.0	2°.068	A	7604	12°.668	Cd_9	3609	63°.628
B	6870	17.4	2.318	a	7164	14.304	N	3582	64.459
C	6563	20.6	2.599	B	6870	15.746	Cd_{10}	3465	69.454
D	5892	18.3	3.104				O	3441	70.587
E	5270	16.0	3.841	C	6563	17.318			
F	4861	11.9	4.587	D_1	5896	21.684	Cd_{11}	3401	72.448
G′	4340	10.1	5.331	D_2	5890	21.727	P	3360	74.571
G	4308	14.5	6.005				Q	3286	78.579
H	4101	13.3	6.754	E	5270	27.543	Cd_{12}	3247	80.459
L	3820	14.0	7.654	F	4862	32.773			
M	3728	10.7	8.100	G	4308	42.604	R	3180	84.972
N	3581	12.9	8.861				Cd_{17}	2747	121.052
P	3361	12.1	9.801	h	4102	47.481	Cd_{18}	2571	143.266
Q	3287	11.9	10.787	H	3969	51.193	Cd_{23}	2312	190.426
R	3180	13.1	11.921	K	3934	52.155			
T	3021	12.8	12.424				Cd_{24}	2264	201.824
Cd_{17}	2747	12.2	13.426	L	3820	55.625	Cd_{25}	2193	220.731
Cd_{18}	2571	11.6	14.965	M	3728	58.894	Cd_{26}	2143	235.972

* The paper is quoted from a paper by Ketteler in Wied. Ann. vol. 21, p. 444.

TABLE 463

ELECTRICAL EQUIVALENTS

Abbreviations: int., international; e.m.u., electromagnetic units; e.s.u., electrostatic units; c.g.s., centimeter-gram-second units. (Taken from Circular 60 of U. S. Bureau of Standards, 1916, Electric Units and Standards, but made consistent with Birge's values, p. 77 et seq.)

RESISTANCE:

1 international ohm =
- 1.00051 absolute ohms
- 1.0001 int. ohms (France, before 1911)
- 1.00016 Board of Trade units (England, 1903)
- 1.01358 B. A. units
- 1.00283 "legal ohms" of 1884
- 1.06300 Siemens units

1 absolute ohm =
- 0.99949 int. ohms
- 1 "practical" e.m.u.
- 10^9 c.g.s. e.m.u.
- 1.11262×10^{-12} c.g.s. e.s.u.

CURRENT:

1 international ampere =
- 0.99995 absolute ampere
- 1.00084 int. amperes (U. S. before 1911)
- 1.00130 int. amperes (England, before 1906)
- 1.00106 int. amperes (England, 1906-08)
- 1.00010 int. amperes (England, 1909-10)
- 1.00032 int. amperes (Germany, before 1911)
- 1.0002 int. amperes (France, before 1911)

1 absolute ampere =
- 1.00005 int. amperes
- 1 "practical" e.m.u.
- 0.1 c.g.s. e.m.u.
- 2.99796×10^9 c.g.s. e.s.u.

ELECTROMOTIVE FORCE:

1 international volt =
- 1.00046 absolute volts
- 1.00084 int. volts (U. S. before 1911)
- 1.00130 int. volts (England, before 1906)
- 1.00106 int. volts (England, 1906-08)
- 1.00010 int. volts (England, 1909-10)
- 1.00032 int. volts (Germany, before 1911)
- 1.00032 int. volts (France, before 1911)

1 absolute volt =
- 0.99954 int. volt
- 1 "practical" e.m.u.
- 10^8 c.g.s. e.m.u.
- 0.00333560 c.g.s. e.s.u.

QUANTITY OF ELECTRICITY:

(Same as current equivalents.)

1 international coulomb =
- 1/3600 ampere-hour
- 1/96494 faraday

CAPACITY:

1 international farad =
- 0.99949 absolute farad

1 absolute farad =
- 1.00051 int. farads
- 1 "practical" e.m.u.
- 10^{-9} c.g.s. e.m.u.
- 8.98776×10^{11} c.g.s. e.s.u.

INDUCTANCE:

1 international henry =
- 1.00051 absolute henries

1 absolute henry =
- 0.99949 int. henry
- 1 "practical" e.m.u.
- 10^9 e.m.u.
- 1.11262×10^{-12} c.g.s. e.s.u.

ENERGY AND POWER:

(standard gravity = 980.665 cm/sec./sec.)

1 international joule =
- 1.00041 absolute joules

1 absolute joule =
- 0.99959 int. joule
- 10^7 ergs
- 0.737560 standard foot-pound
- 0.101972 standard kilogram-meter
- 0.277778×10^{-6} kilowatt-hour

RESISTIVITY:

1 ohm-cm = 0.393700 ohm-inch
- = 10,000 ohm (meter, mm^2)
- = 12,732.4 ohm (meter, mm)
- = 393,700 microhm-inch
- = 1,000,000 microhm-cm
- = 6,015,290 ohm (mil, foot)

1 ohm (meter, gram) = 5710.0 ohm (mile, pound)

MAGNETIC QUANTITIES:

1 int. gilbert = 0.99995 absolute gilbert
1 absolute gilbert = 1.00005 int. gilberts
1 int. maxwell = 1.00046 absolute maxwells
1 absolute maxwell = 0.99954 int. maxwell

1 gilbert = 0.7958 ampere-turn
1 gilbert per cm = 0.7958 ampere-turn per cm
= 2.021 ampere-turns per inch
1 maxwell = 1 line
= 10^{-8} volt-second
1 maxwell per cm^2 = 6.452 maxwells per $in.^2$

Table 464

COMPOSITION AND ELECTROMOTIVE FORCE OF VOLTAIC CELLS

The electromotive forces given in this table approximately represent what may be expected fron cell in good working order, but, with the exception of the standard cells, all of them are subject to co siderable variation.

(*a*) Double Fluid Cells

Name of cell	Negative pole	Solution	Positive pole	Solution	E.m.f in vol
Bunsen	Amalg. Zn	1,H_2SO_4; 12,H_2O	C	Fuming HNO_3	1.94
“	“ “	“	“	HNO_3; dens. 1.38	1.86
Chromate	“ “	12,$K_2Cr_2O_7$; 25,H_2SO_4; 100,H_2O	“	1,H_2SO_4; 12,H_2O	2.00
“	“ “	1,H_2SO_4; 12,H_2O	“	12,$K_2Cr_2O_7$; 100,H_2O	2.03
Daniell	“ “	1,H_2SO_4; 4,H_2O	Cu	Sat. sol. $CuSO_4$; 5,H_2O	1.06
“	“ “	1,H_2SO_4; 12,H_2O	“	“	1.09
“	“ “	5% sol. $ZnSO_4$; 6H_2O	“	“	1.08
“	“ “	1NaCl; 4 parts H_2O	“	“	1.05
Grove	“ “	1H_2SO_4; 12H_2O	Pt	Fuming HNO_3	1.93
“	“ “	Sol. $ZnSO_4$	“	HNO_3; dens. 1.33	1.66
“	“ “	H_2SO_4 sol.; dens. 1.136	“	Concent. HNO_3	1.93
“	“ “	H_2SO_4; dens. 1.136	“	HNO_3; dens. 1.33	1.79
“	“ “	H_2SO_4 sol.; dens. 1.14	“	HNO_3; dens. 1.19	1.66
“	“ “	H_2SO_4 sol.; dens. 1.06	“	“ “ “	1.61
“	“ “	NaCl sol.	“	“ “ 1.33	1.88
Partz	“ “	Sol. $MgSO_4$	“	Sol. $K_2Cr_2O_7$	2.06

(*b*) Single Fluid Cells

Name of cell	Negative pole	Solution	Positive pole	Solution	E.m.f in vol
Leclanche	Amalg. Zn	Sol. NH_4Cl	Carbon*		1.46
Chaperon	“ “	Sol. KOH	Copper**		.98
Edison-Lelande	“ “	“	“		.70
AgCl	Zn	23% sol. NH_4Cl	Silver***		1.02
Law	“	15% “ “	Carbon		1.37
Dry cell	“	1 pt. ZnO, 1 pt. NH_4Cl, 3 pts. plaster of paris, 2 pts. $ZnCl_2$, and water to make a paste	“		1.3
Poggendorff	Amalg. Zn	Sol. $K_2Cr_2O_7$	“		1.08
“	“ “	12$K_2Cr_2O_7$; 25H_2SO_4; 100,H_2O	“		2.01
Regnault	“ “	1H_2SO_4; 12H_2O; 1$CaSO_4$	Cd		.34
Volta couple	Zn	H_2O	Cu		.98

(*c*) Secondary Cells

Name of cell	Negative pole	Solution	Positive pole	Solution	E.m.f in vol
Pb accumulator	Pb	H_2SO_4 sol. of density 1.1	PbO_2		2.2†
Regnier (1)	Cu	$CuSO_4$; H_2SO_4	“		1.68 to .85
“ (2)	Amalg. Zn	$ZnSO_4$ sol.	“ in H_2SO_3		2.36
Main	“ “	H_2SO_4; dens. about 1.1	“ “		2.50
Edison	Fe	KOH 20% sol.	A nickel oxide		1.1 mea

* Depolarizer: Manganese peroxide with powdered carbon. ** Depolarizer: CuO. *** Depolarizer: Silver chloride.

† F. Streintz gives the following value of the temperature variation $\frac{dE}{dt}$ at different stages of charge:

E. M. F.	1.9223	1.9828	2.0031	2.0084	2.0105	2.0779	2.2070
dE/dt × 10⁶	140	228	335	285	255	130	73

Dolezalek gives the following relation between E. M. F. and acid concentration:

Per cent H_2SO_4	64.5	52.2	35.3	21.4	5.2
E. M. F., 0°C	2.37	2.25	2.10	2.00	1.89

Table 465

CONTACT DIFFERENCE OF POTENTIAL IN VOLTS

Solids with Liquids and Liquids with Liquids in Air *

Temperature of substances during experiment about 16° C

	C	Cu	Fe	Pb	Pt	Sn	Zn	Amalg. Zn	Brass	Distilled water
H_2O	.01 to .17	.269 to .100	.148	.171	.285 to .345	.177	−.105 to +.156	.100	.231	...
Alum. sat.sol.	...	—.127	—.653	—.139	.246	—.225	—.536	...	.014	...
$CuSO_4$ sol. sp.gr. 1.087	...	.103	...	...	...	...	...	...	...	...
$CuSO_4$ sat.sol.	...	.070	...	...	...	...	...	...	...	...
Sea salt sol. 1.18 at 20° C	...	—.475	—.605	...	—.856	—.334	—.565	...	—.435	...
NH_4Cl, sat.sol.	...	—.396	—.652	—.189	.059	—.364	—.637	...	—.348	.—
$ZnSO_4$ sol. 1.125 at 4° C	...	...	...	...	...	...	—.238	...	...	...
$ZnSO_4$ sat.sol.	...	...	...	...	...	...	—.430	—.284	...	—.200
One part H_2O + 3, sat. $ZnSO_4$	...	...	...	...	...	...	—.444	...	...	...
Strong H_2SO_4 in water:										
1 to 20 by wt.	...	...	...	...	...	...	—.344	...	...	...
1 to 10 by vol.	about —.035	...	...	...	...	...	...	—.358	...	...
1 to 5 by wt.	...	...	...	...	...	...	...	.429	...	...
5 to 1 by wt.	.01 to 3.0	...	...	—.120	...	—.25	...	...	—.016	...
Con. H_2SO_4	.55 to .85	1.113	...	.72 to 1.252	1.3 to 1.6	...	...	.848	...	1.298
Con. HNO_3	...	...	...	...	.672	...	...	...	...	...

Mercurous sulphate paste, Hg, + .475. Sat.$CuSO_4$sol., H_2O, — .043; sat.$ZnSO_4$sol., + .095; 1 pt. H_2O, 3 pt. $ZnSO_4$ + .102.

Concentrated H_2SO_4, H_2O, + 1.298; sat.alum.sol., + 1.456; $CuSO_4$sat. + 1.269; $ZnSO_4$sat.sol., + 1.699.

* Everett, Units and physical constants: Table of Ayrton and Perry's results, prepared by Ayrton.

DIFFERENCE OF POTENTIAL BETWEEN METALS IN SOLUTIONS OF SALTS

The following numbers are given by G. Magnanini * for the difference of potential in hundredths of a volt between zinc in a normal solution of sulphuric acid and the metals named at the head of the different columns when placed in the solution named in the first column. The solutions were contained in a U-tube, and the sign of the difference of potential is such that the current will flow from the more positive to the less positive through the external circuit.

Strength of the solution in gram molecules per liter.		Zinc.†	Cadmium.†	Lead.	Tin.	Copper.	Silver.
No. of molecules.	Salt.	Difference of potential in centivolts.					
0.5	H_2SO_4	0.0	36.6	51.3	51.3	100.7	121.3
1.0	$NaOH$	—32.1	19.5	31.8	0.2	80.2	95.8
1.0	KOH	—42.5	15.5	32.0	—1.2	77.0	104.0
0.5	Na_2SO_4	1.4	35.6	50.8	51.4	101.3	120.9
1.0	$Na_2S_2O_3$	—5.9	24.1	45.3	45.7	38.8	64.8
1.0	KNO_3	11.8‡	31.9	42.6	31.1	81.2	105.7
1.0	$NaNO_3$	11.5	32.3	51.0	40.9	95.7	114.8
0.5	K_2CrO_4	23.9‡	42.8	41.2	40.9	94.6	121.0
0.5	$K_2Cr_2O_7$	72.8	61.1	78.4	68.1	123.6	132.4
0.5	K_2SO_4	1.8	34.7	51.0	40.9	95.7	114.8
0.5	$(NH_4)_2SO_4$	—0.5	37.1	53.2	57.6‡	101.5	125.7
0.25	$K_4FeC_6N_6$	—6.1	33.6	50.7	41.2	—‡	87.8
0.167	$K_6Fe_2(CN)_{12}$	41.0§	80.8	81.2	130.9	110.7	124.9
1.0	$KCNS$	—1.2	32.5	52.8	52.7	52.5	72.5
1.0	$NaNO_3$	4.5	35.2	50.2	49.0	103.6	104.6?
0.5	$Sr(NO_3)_2$	14.8	38.3	50.6	48.7	103.0	119.3
0.125	$Ba(NO_3)_2$	21.9	39.3	51.7	52.8	109.6	121.5
1.0	KNO_3	—‡	35.6	47.5	49.9	104.8	115.0
0.2	$KClO_3$	15–10‡	39.9	53.8	57.7	105.3	120.9
0.167	$KBrO_3$	13–20‡	40.7	51.3	50.9	111.3	120.8
1.0	NH_4Cl	2.9	32.4	51.3	50.9	81.2	101.7
1.0	KF	2.8	22.5	41.1	50.8	61.3	61.5
1.0	$NaCl$	—	31.9	51.2	50.3	80.9	101.3
1.0	KBr	2.3	31.7	47.2	52.5	73.6	82.4
1.0	KCl	—	32.1	51.6	52.6	81.6	107.6
0.5	Na_2SO_3	—8.2	28.7	41.0	31.0	68.7	103.7
– ‖	$NaOBr$	18.4	41.6	73.1	70.6 ‡	89.9	99.7
1.0	$C_4H_6O_6$	5.5	39.7	61.3	54.4§	104.6	123.4
0.5	$C_4H_6O_6$	4.1	41.3	61.6	57.6	110.9	125.7
0.5	$C_4H_4KNaO_6$	—7.9	31.5	51.5	42–47	100.8	119.7

* "Rend. della R. Acc. di Roma," 1890.
† Amalgamated.
‡ Not constant.
§ After some time.
‖ A quantity of bromine was used corresponding to NaOH = 1.

TABLE 467

THERMOELECTRIC POWER

The thermoelectric power of a circuit of two metals is the electromotive force produced by one degree C difference of temperature between the junctions. The thermoelectric power varies with the temperature, thus: thermoelectric power $= Q = dE/dt = A + Bt$, where A is the thermoelectric power at 0° C, B is a constant, and t is the mean temperature of the junctions. The neutral point is the temperature at which $dE/dt = 0$, and its value is $-A/B$. When a current is caused to flow in a circuit of two metals originally at a uniform temperature, heat is liberated at one of the junctions and absorbed at the other. The rate of production or liberation of heat at each junction, or Peltier effect, is given in calories per second, by multiplying the current by the coefficient of the Peltier effect. This coefficient in calories per coulomb $= QT/\mathcal{J}$, in which Q is in volts per degree C, T is the absolute temperature of the junction, and $\mathcal{J} = 4.19$. Heat is also liberated or absorbed in each of the metals as the current flows through portions of varying temperature. The rate of production or liberation of heat in each metal, or the Thomson effect, is given in calories per second by multiplying the current by the coefficient of the Thomson effect. This coefficient, in calories per coulomb $= BT\theta/\mathcal{J}$, in which B is in volts per degree C, T is the mean absolute temperature of the junctions, and θ is the difference of temperature of the junctions. (BT) is Sir W. Thomson's "Specific Heat of Electricity." The algebraic signs are so chosen in the following table that when A is positive, the current flows in the metal considered from the hot junction to the cold. When B is positive, Q increases (algebraically) with the temperature. The values of A, B, and thermoelectric power in the following table are *with respect to lead* as the other metal of the thermoelectric circuit. The thermoelectric power of a couple composed of two metals, 1 and 2, is given by subtracting the value for 2 from that for 1; when this difference is positive, the current flows from the hot junction to the cold in 1. In the following table, A is given in microvolts per degree, B in microvolts per degree per degree, and the neutral point in degrees.

The table has been compiled from the results of Becquerel, Matthiessen and Tait; in reducing the results, the electromotive force of the Grove and Daniell cells has been taken as 1.95 and 1.07 volts. The value for constantan was reduced from results given in Landolt-Börnstein's tables. The thermoelectric powers of antimony and bismuth alloys are given by Becquerel in the reference given below.

Substance.	A Microvolts.	B Microvolts.	Thermoelectric power at mean temp. of junctions (microvolts).		Neutral point $-\frac{A}{B}$	Authority.
			20° C	50° C		
Aluminum	−0.76	+0.0039	−0.68	−0.56	+195	T
Antimony, comm'l pressed wire	—	—	+6.0	—	—	M
" axial	—	—	+22.6	—	—	"
" equatorial	—	—	+26.4	—	—	"
Argentan	−11.94	−0.0506	−12.95	−14.47	−236	T
"	—	—	—	−12.7	—	B
Arsenic	—	—	−13.56	—	—	M
Bismuth, comm'l pressed wire	—	—	−97.0	—	—	"
" pure " "	—	—	−89.0	—	—	"
" crystal, axial	—	—	−65.0	—	—	"
" " equatorial	—	—	−45.0	—	—	"
Cadmium	+2.63	+0.0424	+3.48	+4.75	−62	T
" fused	—	—	—	+2.45	—	B
Calcium	—	—	—	+8.9	—	S'
Cobalt	—	—	−22	—	—	M
Constantan	—	—	—	−19.3	—	—
Copper	+1.34	+0.0094	+1.52	+1.81	−143	T
" commercial	—	—	+0.10	—	—	M
" galvanoplastic	—	—	+3.8	—	—	"
Gallium	—	—	−0.2	—	—	S
Gold	+2.80	+0.0101	+3.0	+3.30	[−277]	T
Iron	+17.15	−0.0482	+16.2	+14.74	+356	T
" pianoforte wire	—	—	+17.5	—	—	M
" commercial	—	—	—	+12.10	—	B
" "	—	—	—	+9.10	—	"
Lead	—	0.0000	−0.00	0.00	—	—
Magnesium	+2.22	−0.0094	+2.03	+1.75	+236	T
Molybdenum	—	—	+5.9	—	—	S
Mercury	—	—	−0.413	−3.30	—	MB
Nickel	—	—	—	−15.50	—	B
" (−18° to 175°)	−21.8	−0.0506	−22.8	−24.33	[−431]	T
" (250°–300°)	−83.57	+0.2384	—	—	—	"
" (above 340°)	−3.04	−0.0506	—	—	—	"

TABLE 467 (*continued*).—Thermoelectric Power

Substance.	A Microvolts.	B Microvolts.	Thermoelectric power at mean temp. of junctions (microvolts). 20° C	50° C	Neutral point $-\frac{A}{B}$	Authority.
Palladium	−6.18	−0.0355	−6.9	−7.96	−174	T
Phosphorus (red)	–	–	+29.9	–	–	M
Platinum	–	–	+0.9	–	–	"
" (hardened)	+2.57	−0.0074	+2.42	+2.20	347	T
" (malleable)	−0.60	−0.0109	−.818	−1.15	−55	"
" wire	–	–	–	+0.94	–	B
" another specimen	–	–	–	−2.14	–	"
Platinum-iridium alloys:						
85% Pt + 15% Ir	+7.90	+0.0062	+8.03	+8.21	[−1274]	T
90% Pt + 10% Ir	+5.90	−0.0133	+5.63	+5.23	444	"
95% Pt + 5% Ir	+6.15	+0.0055	+6.26	+6.42	[−1118]	"
Selenium	–	–	+807.	–	–	M
Silver	+2.12	+0.0147	+2.41	+2.86	−144	T
" (pure hard)	–	–	+3.00	–	–	M
" wire	–	–	–	+2.18	–	B
Steel	+11.27	−0.0325	+10.62	+9.65	347	T
Tantalum	–	–	−2.6	–	–	–
Tellurium β	–	–	+500.	–	–	H
" α	–	–	+160.	–	–	H
Thallium	–	–	+0.8	–	–	–
Tin (commercial)	–	–	–	+0.33	–	H
"	–	–	+0.1	–	–	M
"	−0.43	+0.0055	−0.33	−0.16	78	T
Tungsten	–	–	−2.0	–	–	–
Zinc	+2.32	+0.0238	+2.79	+3.51	−98	T
" pure pressed	–	–	+3.7	–	–	M

B Ed. Becquerel, "Ann. de Chim. et de Phys." [4] vol. 8. S. Bureau of Standards.
M Matthiesen, "Pogg. Ann." vol. 103, reduced by Fleming Jenkin.
T Tait, "Trans. R. S. E." vol. 27, reduced by Mascart.
H Haken, Ann. der Phys. 32, p. 291, 1910. (Electrical conductivity of Teβ = 0.04, Teα 1.7 c. m. units.) Swisher, 1917.

TABLE 468.—Thermoelectric Power of Alloys

The thermoelectric powers of a number of alloys are given in this table, the authority being Ed. Becquerel. They are relative to lead, and for a mean temperature of 50° C. In reducing the results from copper as a reference metal, the thermoelectric power of lead to copper was taken as − 1.9.

Substance.	Relative quantity.	Thermoelectric power in microvolts.
Antimony Cadmium	806 696	227
Antimony Cadmium Zinc	4 2 1	146
Antimony Cadmium Bismuth	806 696 121	137
Antimony Zinc	806 406	95
Antimony Zinc Bismuth	806 406 121	8.1
Antimony Cadmium Lead Zinc	4 2 1 1	76
Antimony Cadmium Zinc Tin	4 2 1 1	46

Substance.	Relative quantity.	Thermoelectric power in microvolts.
Antimony Zinc Tin	2 1 1	43
Antimony Cadmium Zinc	12 10 3	35
Antimony Tellurium	10 1	10.2
Antimony Bismuth	10 1	8.8
Antimony Iron	4 1	2.5
Antimony Magnesium	8 1	1.4
Antimony Lead	8 1	−0.4
Bismuth	–	−43.8
Bismuth Antimony	2 1	−33.4

Substance.	Relative quantity.	Thermoelectric power in microvolts.
Bismuth Antimony	4 1	−51.4
Bismuth Antimony	8 1	−63.2
Bismuth Antimony	10 1	−68.2
Bismuth Antimony	12 1	−66.9
Bismuth Tin	2 1	60
Bismuth Selenium	10 1	−24.5
Bismuth Zinc	12 1	−31.1
Bismuth Arsenic	12 1	−46.0
Bismuth Bismuth sulphide	1 1	68.1

TABLE 469.—Thermal Electromotive Force of Metals and Alloys versus Platinum (millivolts)

One junction is supposed to be at 0° C; + indicates that the current flows from the 0° junction into the platinum. The rhodium and iridium were rolled, the other metals drawn.*

Temperature, ° C.	Au.	Ag.	90%Pt+10%Pd.	10%Pt+90%Pd.	Pd.	90%Pt+10%Rh.	90%Pt+10%Ru.	Ir.	Rh.
−185	−0.15	−0.16	−0.11	+0.24	+0.77	-	−0.53	−0.28	−0.24
−80	−0.31	−0.30	−0.09	+0.15	+0.39	-	−0.39	−0.32	−0.31
+100	+0.74	+0.72	+0.26	−0.19	−0.56	-	+0.73	+0.65	+0.65
+200	+1.8	+1.7	+0.62	−0.31	−1.20	-	+1.6	+1.5	+1.5
+300	+3.0	+3.0	+1.0	−0.37	−2.0	+2.3	+2.6	+2.5	+2.6
+400	+4.5	+4.5	+1.5	−0.35	−2.8	+3.2	+3.6	+3.6	+3.7
+500	+6.1	+6.2	+1.9	−0.18	−3.8	+4.1	+4.6	+4.8	+5.1
+600	+7.9	+8.2	+2.4	+0.12	−4.9	+5.1	+5.7	+6.1	+6.5
+700	+9.9	+10.6	+2.9	+0.61	−6.3	+6.2	+6.9	+7.6	+8.1
+800	+12.0	+13.2	+3.4	+1.2	−7.9	+7.2	+8.0	+9.1	+9.9
+900	+14.3	+16.0	+3.8	+2.1	−9.6	+8.3	+9.2	+10.8	+11.7
+1000	+16.8	-	+4.3	+3.1	−11.5	+9.5	+10.4	+12.6	+13.7
+1100	-	-	+4.8	+4.2	−13.5	+10.6	+11.6	+14.5	+15.8
+(1300)	-	-	-	-	-	+13.1	+14.2	+18.6	+20.4
+(1500)	-	-	-	-	-	+15.6	+16.9	+23.1	+25.6

* Holborn and Day.

TABLE 470.—Thermal Electromotive Force of Platinum-Rhodium Alloys versus Platinum

Temperature versus Electromotive Force in Millivolts

	Per Cent Rhodium							
Temp. °C	0.5	1.0	5.0	10.0	20.0	40.0	80.0	100.0 *
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	+0.10	+0.18	+0.54	+0.64	+0.63	+0.65	+0.62	+0.70
200	.20	.37	1.16	1.43	1.44	1.52	1.49	1.61
300	.29	.57	1.82	2.32	2.40	2.55	2.55	2.68
400	.39	.76	2.49	3.25	3.47	3.70	3.77	3.91
500	.48	.94	3.17	4.22	4.63	4.97	5.12	5.28
600	.58	1.12	3.86	5.22	5.87	6.36	6.60	6.77
700	.67	1.30	4.55	6.26	7.20	7.85	8.20	8.40
800	.76	1.48	5.25	7.33	8.59	9.45	9.92	10.16
900	.85	1.66	5.96	8.43	10.06	11.16	11.76	12.04
1000	.94	1.84	6.68	9.57	11.58	12.98	13.73	14.05
1100	1.03	2.02	7.42	10.74	13.17	14.90	15.81	16.18
1200	1.13	2.20	8.16	11.93	14.84	16.91	17.99	18.42

* Bur. Standards Journ. Res., 3, 1029, 1929.

TABLE 471.—Thermal Electromotive Force of Aluminum versus Platinum *

Temperature versus Electromotive Force

°C	Intern. mv	°C	Intern. mv	°C	Intern. mv
0	0.000	240	1.374	480	3.703
20	+0.062	260	1.538	500	3.931
40	0.135	280	1.708	520	4.164
60	0.218	300	1.884	540	4.403
80	0.312	320	2.065	560	4.647
100	0.416	340	2.252	580	4.896
120	0.529	360	2.444	600	5.150
140	0.651	380	2.641	620	5.409
160	0.781	400	2.843	640	5.673
180	0.919	420	3.050	660	5.942
200	1.064	440	3.262		
220	1.216	460	3.480		

* Bur. Standards Circ. 346, 1927.

TABLE 472.—Thermal Electromotive Force of Zinc versus Platinum

Temperature versus Electromotive Force

°C	Intern. mv	°C	Intern. mv	°C	Intern. mv
0	0.000	150	1.276	300	3.417
25	+0.153	175	1.572	325	3.853
50	0.331	200	1.894	350	4.310
75	0.533	225	2.240	375	4.786
100	0.758	250	2.610	400	5.290
125	1.005	275	3.002	415	5.604

TABLE 473.—Thermal Electromotive Force of Cadmium versus Platinum

Temperature versus Electromotive Force

°C	Intern. mv	°C	Intern. mv	°C	Intern. mv
0	0.000	125	1.211	250	3.255
25	+0.171	150	1.559	275	3.740
50	0.378	175	1.940	300	4.238
75	0.620	200	2.351	315	4.539
100	0.898	225	2.790		

TABLE 474.—Thermal Electromotive Force of Nickel versus Platinum *

Temperature versus Electromotive Force

°C	Intern. mv	°C	Intern. mv	°C	Intern. mv
0	0.000	400	5.450	800	9.350
25	−0.350	425	5.580	825	9.675
50	0.710	450	5.745	850	10.010
75	1.090	475	5.960	875	10.350
100	1.485	500	6.165	900	10.695
125	1.880	525	6.360	925	11.045
150	2.285	550	6.585	950	11.400
175	2.695	575	6.800	975	11.765
200	3.105	600	7.040	1000	12.130
225	3.505	625	7.290	1025	12.500
250	3.890	650	7.550	1050	12.875
275	4.255	675	7.825	1075	13.250
300	4.590	700	8.105	1100	13.625
325	4.880	725	8.415		
350	5.110	750	8.720		
375	5.290	775	9.030		

* Bur. Standards Journ. Res., 5, 1291, 1930.

TABLE 475.—Thermoelectric Properties at Low Temperatures

(Borelius, Keesom, Johansson, Linde, Com. Phys. Lab. Leiden, no. 206, 1930.)

Thermoelectric Force in Microvolts per °K. against Silver Alloy

°C	Cu	Ag	Au	Pd	Pt	Fe	Pb
−255	+0.07	−0.10	−1.20	+0.75	+1.54	+0.05	−1.06
−240	0.45	+0.37	−0.05	2.10	3.60	1.40	−1.19
−220	0.90	0.39	+0.24	3.40	5.24	4.80	−1.25
−200	0.89	0.31	0.30	3.48	5.40	8.45	−1.29
−180	0.72	0.25	0.30	2.14	4.36	11.5	−1.33
−160	0.61	0.22	0.33	0.54	3.02	14.0	−1.42
−140	0.52	0.21	0.37	−1.06	1.72	15.8	−1.54
−120	0.47	0.20	0.40	−2.52	0.50	16.9	−1.67
−100	0.44	0.20	0.44	−3.92	−0.70	17.5	−1.79
−80	0.45	0.20	0.47	−5.27	−1.76	17.5	−1.92
−60	0.47	0.20	0.51	−6.52	−2.80	17.3	−2.05
−40	0.49	0.20	0.55	−7.80	−3.80	16.9	−2.17
−20	0.51	0.20	0.58	−9.05	−4.72	16.2	−2.29
0	0.53	0.21	0.62	−10.32	−5.62	15.8	−2.42
+20	0.56	0.22	0.65	−11.6	−6.56	15.3	−2.54

TABLE 476.—Thomson Effect in Microvolts per Degree

°K.	Cu	Ag	Au	Pd	Pt	Fe	Ni	Co	Pb
20	+0.59	+1.40	+2.83	+1.9	+3.2	+1.3	...	...	....
25	1.04	1.23	2.09	2.6	3.6	2.7	...	...	....
30	1.22	0.85	1.58	3.1	3.9	4.1	−4.5	−0.2	0.00
40	1.03	0.24	0.88	3.2	3.8	6.7	−5.4	−0.3	−0.04
50	0.67	−0.02	0.45	2.5	2.7	9.0	−5.0	−0.8	−0.06
60	0.18	−0.17	0.19	1.0	1.0	10.8	−4.5	−2.0	−0.09
70	−0.29	−0.24	0.07	−1.5	−1.1	11.9	−4.1	−3.7	−0.12
80	−0.46	−0.25	0.05	−4.6	−3.3	12.6	−4.0	−5.5	−0.15
90	−0.48	−0.17	0.17	−6.6	−5.1	12.9	−4.0	−7.0	−0.18
100	−0.45	−0.03	0.32	−7.8	−6.5	13.0	−4.5	−8.4	−0.20
110	−0.37	+0.12	0.45	−8.7	−7.5	13.0	−5.3	−9.8	−0.23
120	−0.26	0.25	0.56	−9.3	−8.0	12.8	−6.4	−11.1	−0.26
130	−0.13	0.35	0.66	−9.7	−8.2	12.2	−7.4	−12.4	−0.29
140	+0.02	0.44	0.75	−10.1	−8.2	11.0	−8.3	−13.5	−0.32
150	0.17	0.52	0.83	−10.3	−8.3	8.9	−9.0	−14.6	−0.34
160	0.31	0.59	0.91	−10.6	−8.4	6.1	−9.7	−15.7	−0.37
170	0.46	0.66	0.99	−10.9	−8.5	2.6	−10.3	−16.7	−0.40
180	0.59	0.72	1.06	−11.2	−8.7	−0.2	−10.9	−17.6	−0.42
200	0.79	0.84	1.19	−12.1	−9.1	−3.5	−12.1	−19.6	−0.46
220	0.96	0.96	1.31	−13.3	−9.8	−4.5	−13.3	−21.5	−0.49
240	1.10	1.08	1.43	−14.6	−10.6	−4.8	−14.5	−23.4	−0.52
260	1.24	1.20	1.54	−15.8	−11.4	−5.2	−15.7	−25.4	−0.54
280	1.38	1.32	1.66	−17.0	−12.3	−5.6	....	....	−0.55
300	+1.52	+1.44	+1.77	−18.2	−13.2	−5.9	....	....	−0.57

TABLE 477.—Peltier Effect

The coefficient of Peltier effect may be calculated from the constants A and B of Table 467, as there shown. With Q (see Table 467) in microvolts per °C and T= absolute temperature (K), the coefficient of Peltier effect= $\frac{QT}{42}$ cal. per coulomb=0.00086 QT cal. per ampere-hour=$QT/1000$ millivolts (=millijoules per coulomb). Experimental results, expressed in slightly different units, are here given. The figures are for the heat production at a junction of copper and the metal named, in calories per ampere-hour. The current flowing from copper to the metal named, a positive sign indicates a warming of the junction. The temperature not being stated by either author, and Le Roux not giving the algebraic signs, these results are not of great value.

	Calories per ampere-hour.										
	Sb. ‡	Sb. commercial.	Bi. pure.	Bi. §	Cd.	German Silver.	Fe.	Ni.	Pt.	Ag.	Zn.
Jahn* . .	-	-	-	-	—.62	-	—3.61	4.36	0.32	—.41	—.58
Le Roux† .	13.02	4.8	19.1	25.8	0.46	2.47	2.5	-	-	-	.39

* "Wied. Ann." vol. 34, p. 767.
† "Ann. de Chim. et de Phys." (4) vol. 10, p. 201.
‡ Becquerel's antimony is 806 parts Sb + 406 parts Zn + 121 parts Bi.
§ Becquerel's bismuth is 10 parts Bi + 1 part Sb.

TABLE 478.—Peltier Effect, Fe-Constantan, Ni-Cu, 0° — 560°C

Temperature.	0°	20°	130°	240°	320°	560°	
Fe-Constantan . . .	3.1	3.6	4.5	6.2	8.2	12.5	g. cal. $\times 10^{-3}$
Ni-Cu	1.92	2.15	2.45	2.06	1.91	2.38	per coulomb.

TABLE 479.—Peltier Electromotive Force in Millivolts

Metal against Copper.	Sb.	Fe.	Cd.	Zn.	Ag.	Au.	Pb.	Sn.	Al.	Pt.	Pd.	Ni.	Bi.
Le Roux .	—5.64	—2.93	—.53	—.45	-	-	-	-	-	-	-	-	+22.3
Jahn . . .	-	—3.68	—.72	—.68	—.48	-	-	-	-	+.37	-	+5.07	-
Edlund . .	-	—2.96	—.16	—.01	+.03	+.33	+.50	+.56	+.70	+1.02	+2.17	-	+17.7
Caswell . .	-	-	-	-	+.03	-	-	-	+.70	+.85	-	+6.0	+16.1

Le Roux, 1867; Jahn, 1888; Edlund, 1870-71; Caswell, Phys. Rev. 33, p. 381, 1911.

TABLE 480.—Thermoelectric Power; Pressure Effects

The following values of the thermoelectric powers under various pressures are taken from Bridgman, Pr. Am. Acad. Arts and Sc. 53, p. 269, 1918. A positive emf means that the current at the hot junction flows from the uncompressed to the compressed metal. The cold junction is always at 0° C. The last two columns give the constants in the equation E = thermoelectric force against lead (0° to 100° C) = $(At + Bt^2) \times 10^{-6}$ volts, at atmospheric pressure, a positive emf meaning that the current flows from lead to the metal under consideration at the hot junction.

Metal.	Thermo-electric force, volts × 10^9									Formula coefficients.	
	Pressure, kg/cm²										
	2000		4000		8000		12,000				
	Temperature, ° C										
	50°	100°	50°	100°	50°	100°	20°	50°	100°	A	B
Bi †	53,000	85,000	110,000	185,000	255,000	425,000	185,000	452,000	710,000	−74.42	+.0160
Zn †	6,200	14,100	13,000	28,500	26,100	58,100	14,400	38,500	87,400	+3.047	−.00495
Tl ‡	4,930	10,870	9,380	20,290	17,170	37,630	8,780	23,750	52,460	+1.659	−.00134 [1]
Cd †	2,040	7,120	4,620	14,380	10,960	28,740	6,680	19,180	45,560	+12.002	+.1619
Constantan ‡	2,850	5,950	5,800	11,810	11,530	23,790	6,750	17,200	35,470	−34.76	−.0397
Pd *	2,190	4,380	4,400	8,800	8,630	17,690	5,090	12,970	26,520	−5.496	−.01760
Pt *	1,810	3,600	3,600	7,310	7,370	14,350	3,880	11,030	21,570	−3.092	−.01334
W ‡	1,190	2,530	2,360	4,990	4,690	10,120	2,700	7,050	15,140	+1.594	+.01705
Ni *	700	1,680	1,500	3,400	3,230	7,190	1,880	5,140	11,440	−17.61	−.0178
Ag *	840	1,870	1,720	3,720	3,350	7,190	+1,900	4,950	10,560	+2.556	+.00432
§ Fe †	390	1,670	590	3,250	5,300	5,820	−990	220	7,680	+16.18	−.0089 [2]
Pb ‡	460	1,050	920	2,120	1,860	4,210	+880	281	6,330	—	—
Au *	456	1,052	905	2,051	1,791	3,974	+990	2,627	5,760	+2.899	+.00467 [3]
Cu †	+292	584	+580	1,216	1,124	2,420	+596	1,616	3,546	+2.777	+.00483
§ Al †	−70	101	−91	294	32	929	−68	312	1,962	−0.416	+.00008 [4]
§ Mo ‡	+93	140	+187	278	375	555	+146	562	833	+5.892	+.02167 [5]
§ Sn †	+38	+87	+58	+165	+70	+292	−182	+10	+390	+0.230	−.00067
Manganin †	−123	−232	−242	−452	−489	−894	−308	−719	−1,314	+1.366	+.000414 [6]
Mg †	−84	−167	−181	−362	−395	−791	−259	−648	−1,296	−0.095	+.00004
Co †	−156	−348	−316	−692	−630	−1,360	−352	−937	−2,061	−17.32	−.0390

* Identical wire of Table 485. † Another wire of same sample. ‡ Different sample.
§ Results too irregular for interpolation for values at other temperature and pressures; see original article.
(1) $-.0_5 56t^3$; (2) $-.0_4 86t^3$, annealed ingot iron; (3) $-.0_5 166t^3$; (4) $-.0_4 1t^3$; (5) $-.0_4 25t^3$; (6) $-.0_4 112t^3$.

TABLE 481.—Peltier and Thomson Heats; Pressure Effects

The following data indicate the magnitude of the effect of pressure on the Peltier and Thomson heats. They refer to the same samples as for the last table. The Peltier heat is considered positive if heat is absorbed by the positive current from the surroundings on flowing from uncompressed to compressed metal. A positive d^2E/dt^2 means a larger Thomson heat in the compressed metal, and the Thomson heat is itself considered positive if heat is absorbed by the positive current in flowing from cold to hot metal. Same reference and notes as for preceding table.

Metal.	Peltier heat, 10^6 × Joules/coulomb.						Thomson heat, 10^8 × Joules/coulomb/° C					
	Pressure kg/cm²						Pressure kg/cm²					
	6000			12,000			6000			12,000		
	Temperature ° C						Temperature ° C					
	0°	50°	100°	0°	50°	100°	0°	50°	100°	0°	50°	100°
§ Bi †	+1070	+1210	—	+2580	+2810	—	+1150	+650	—	−520	−405	—
§ Zn †	+98	+140	+190	+190	+278	+412	+41	+48	+56	+63	+133	+220
§ Tl ‡	+66	+95	+124	+112	+171	+229	+38	+28	+26	+79	+63	+50
§ Cd †	+19	+71	+118	+81	+148	+221	+109	+74	+63	+105	+92	+93
Constantan ‡	+46	+57	+70	+90	+114	+140	+5	+6	+6	+13	+14	+17
§ Pd *	+35	+43	+52	+68	+86	+103	+3	+4	+4	+9	+9	+8
§ Pt *	+23	+37	+35	+45	+76	+65	+49	−6	−18	+96	+17	+59
§ W ‡	+17	+25	+32	+36	+49	+65	+8	+7	+6	+9	+14	+20
§ Ni *	+11	+17	+23	+24	+37	+50	+9	+7	+8	+16	+15	+10
Ag *	+13	+17	+23	+25	+34	+44	+4	+5	+6	+7	+8	+10
§ Fe †	−11	+18	+15	−38	+38	+36	+79	+58	−121	−347	+120	−194
Pb ‡	+7	+10	+16	+14	+20	+30	+2	+6	+10	+6	+8	+20
Au *	+6	+10	+14	+13	+18	+25	+4	+4	+5	+6	+6	+7
Cu †	+4	+6	+8	+8	+11	+16	+4	+1	+4	+6	+3	+8
§ Al †	−2	+2	+8	−3	+7	+17	+6	+9	+11	+21	+16	+20
§ Mo ‡	+1	+2	+0	+2	+4	+1	+1	−5	−1	+2	−11	−2
§ Sn †	−1	+1	+1	−5	+2	+2	+6	+0	−1	+29	+2	−5
§ Manganin †	−2	−2	−2	−4	−4	−4	+1	+1	+0	+2	+1	+1
Mg †	−16	−18	−21	−35	−42	−48	0	0	0	0	0	0
§ Co †	−23	−33	−44	−46	−67	−90	−14	−11	−10	−20	−24	−28

* † ‡ § Same significance as in preceding table.

TABLE 482

THE TRIBO-ELECTRIC SERIES

In the following table it is so arranged that any material in the list becomes positively electrified when rubbed by one lower in the list. The phenomenon depends upon surface conditions and circumstances may alter the relative positions in the list.

1 Asbestos (sheet).
2 Rabbit's fur, hair, (Hg).
3 Glass (combn. tubing).
4 Vitreous silica, opossum's fur.
5 Glass (fusn.).
6 Mica.
7 Wool.
8 Glass (pol.), quartz (pol.), glazed porcelain.
9 Glass (broken edge), ivory.
10 Calcite.
11 Cat's fur.
12 Ca, Mg, Pb, fluor spar, borax.
13 Silk.
14 Al, Mn, Zn, Cd, Cr, felt, hand, wash-leather.
15 Filter paper.
16 Vulcanized fiber.
17 Cotton.
18 Magnalium.
19 K-alum, rock-salt, satin spar.
20 Woods, Fe.
21 Unglazed porcelain, sal-ammoniac.
22 K-bichromate, paraffin, tinned-Fe.
23 Cork, ebony.
24 Amber.
25 Slate, chrome-alum.
26 Shellac, resin, sealing-wax.
27 Ebonite.
28 Co, Ni, Sn, Cu, As, Bi, Sb, Ag, Pd, C, Te, Eureka, straw, copper sulphate, brass.
29 Para rubber, iron alum.
30 Guttapercha.
31 Sulphur.
32 Pt, Ag, Au.
33 Celluloid.
34 Indiarubber.

Shaw, Pr. Roy. Soc. 94, p. 16, 1917; the original article shows the alterations in the series sequence due to varied conditions.

TABLE 483

AUXILIARY TABLE FOR COMPUTING WIRE RESISTANCES

For computing resistance in ohms per meter from resistivity, ρ, in michroms per cm. cube (see Table 484, etc.). *e. g.* to compute for No. 23 copper wire when $\rho = 1.724$: 1 meter $= 0.0387 + .0271 + .0008 + .0002 = 0.0668$ ohms; for No. 11 lead wire when $\rho = 20.4$; 1 meter $= 0.0479 + .0010 = 0.0489$ ohms. The following relation allows computation for wires of other gage numbers: resistance in ohms per meter of No. N $= 2(n - 3)$ within 1 %: *e. g.* resistance of meter of No. 18 $= 2 \times$ No. 15.

Gage No.	Diam. in mm.	Section mm².	ρ in micro-ohms per cm. cube.									
			1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
			Resistance of wire 1 meter long in ohms.									
0000	11.7	107.2	$.0_4933$	$.0_3187$	$.0_3280$	$.0_3373$	$.0_3466$	$.0_3560$	$.0_3653$	$.0_3746$	$.0_3840$	$.0_3933$
00	9.27	67.43	$.0_3148$	$.0_3297$	$.0_3445$	$.0_3593$	$.0_3742$	$.0_3890$	$.0_2104$	$.0_2119$	$.0_2133$	$.0_2148$
1	7.35	42.41	$.0_3236$	$.0_3472$	$.0_3707$	$.0_3943$	$.0_2118$	$.0_2141$	$.0_2165$	$.0_2189$	$.0_2212$	$.0_2236$
3	5.83	26.67	$.0_3375$	$.0_3750$	$.0_2112$	$.0_2150$	$.0_2187$	$.0_2225$	$.0_2262$	$.0_2300$	$.0_2337$	$.0_2375$
5	4.62	16.77	$.0_3596$	$.0_2119$	$.0_2179$	$.0_2239$	$.0_2298$	$.0_2358$	$.0_2417$	$.0_2477$	$.0_2537$	$.0_2596$
7	3.66	10.55	$.0_3948$	$.0_2190$	$.0_2284$	$.0_2379$	$.0_2474$	$.0_2569$	$.0_2664$	$.0_2758$	$.0_2853$	$.0_2948$
9	2.91	6.634	$.0_2151$	$.0_2301$	$.0_2452$	$.0_2603$	$.0_2754$	$.0_2904$	.0106	.0121	.0136	.0151
11	2.30	4.172	$.0_2240$	$.0_2479$	$.0_2719$	$.0_2959$	.0120	.0144	.0168	.0192	.0216	.0240
13	1.83	2.624	$.0_2381$	$.0_2762$	.0114	.0152	.0191	.0229	.0267	.0305	.0343	.0381
15	1.45	1.650	$.0_2606$	.0121	.0182	.0242	.0303	.0364	.0424	.0485	.0545	.0606
17	1.15	1.038	$.0_2963$	.0193	.0289	.0385	.0482	.0578	.0674	.0771	.0867	.0963
19	.912	.6527	.0153	.0306	.0460	.0613	.0766	.0919	.1072	.1226	.1379	.1532
21	.723	.4105	.0244	.0487	.0731	.0974	.1218	.1462	.1705	.1949	.2192	.2436
23	.573	.2582	.0387	.0775	.1162	.1549	.1936	.2324	.2711	.3098	.3486	.3873
25	.455	.1624	.0616	.1232	.1847	.2463	.3079	.3695	.4310	.4926	.5542	.6158
27	.361	.1021	.0979	.1959	.2938	.3918	.4897	.5877	.6856	.7835	.8815	.9794
29	.286	.0642	.1557	.3114	.4671	.6228	.7786	.9343	1.090	1.246	1.401	1.557
31	.227	.0404	.2476	.4952	.7428	.9904	1.238	1.486	1.733	1.981	2.228	2.476
33	.180	.0254	.3937	.7874	1.181	1.575	1.968	2.362	2.756	3.150	3.543	3.937
35	.143	.0160	.6262	1.252	1.879	2.505	3.131	3.757	4.383	5.009	5.636	6.262
37	.113	.0100	.9950	1.990	2.985	3.980	4.975	5.970	6.965	7.960	8.955	9.950
39	.090	.0063	1.583	3.166	4.748	6.331	7.914	9.497	11.08	12.66	14.25	15.83
40	.080	.0050	1.996	3.992	5.988	7.984	9.980	11.98	13.97	15.97	17.96	19.96

TABLE 484

RESISTIVITY OF METALS AND SOME ALLOYS

The resistivities are the values of ρ in the equation $R = \rho l/s$, where R is the resistance in microhms of a length l cm of uniform cross section s cm². The temperature coefficient is a_s in the formula $R_t = R_s[1 + a_s(t - t_s)]$. The information of column 2 does not necessarily apply to the temperature coefficient. See also next table for temperature coefficients 0° to 100°C, also page 413 for values on metals of high purity.

Substance	Remarks	Temperature °C	Microhm-cm	Reference	Temperature coefficient		
					t_s	a_s	Reference
Advance	see constantan	—	—	—	—	—	—
Aluminum	see p. 421	20	2.828	1	18°	+0.0039	2
"	c. p.	−189	.64	3	25	+ .0034	4
"	"	−100	1.53	3	100	+ .0040	4
"	"	0	2.62	3	500	+ .0050	4
"	"	+100	3.86	3	—	—	—
"	"	400	8.0	3	—	—	—
Antimony	—	0	39.1	30	20	+ .0036	5
"	—	−190	10.5	6	—	—	—
"	liquid	+860	120	7	—	—	—
Arsenic	—	0	35	8	—	—	—
Beryllium	—	20	10.1	31	—	—	—
Bismuth	—	18	119.0	9	20	+ .004	5
"	—	100	160.2	9	—	—	—
Brass	—	20	7	5	20	+ .002	5
Cadmium	drawn	−160	2.72	10	20	+ .0038	5
"	"	18	7.54	9	—	—	—
"	"	100	9.82	9	—	—	—
"	liquid	318	34.1	11	—	—	—
Caesium	—	−187	5.25	12	—	—	—
"	—	0	19	11	—	—	—
"	solid	27	22.2	13	—	—	—
"	liquid	30	36.6	13	—	—	—
Calcium	99.57 pure	20	4.59	14	—	+ .0036	14
Calido	see constantan	—	—	—	—	—	—
Chromium	—	0	2.6	15	—	—	—
Climax	—	20	87	5	20	+ .0007	5
Cobalt	99.8 pure	20	9.7	16	—	—	—
Constantan	60% Cu, 40% Ni	20	49	5	12	+ .000008	4
"	—	—	—	—	25	+ .000002	4
"	—	—	—	—	100	− .000033	4
"	—	—	—	—	200	− .000020	4
"	—	—	—	—	500	+ .000027	4
Copper	annealed	20	1.724	1	20 see col. 2	+ .00393	5
"	hard-drawn	20	1.77	1	" " " "	+ .00382	5
"	electrolytic	−206	.144	17	100	+ .0038	4
"	"	+205	2.92	17	400	+ .0042	4
"	pure	400	4.10	3	1000	+ .0062	4
"	very pure, ann'ld	20	1.692	18	—	—	—
Eureka	see constantan	—	—	—	—	—	—
Excello	—	20	92	5	20	+ .00016	5
Gallium	—	0	53	12	—	—	—
German silver	18% Ni	20	33	5	20	+ .0004	5
Germanium	—	0	89000.	32	—	—	—
Gold	99.9 pure	−183	.68	17	20	+ .0034	5
"	—	0	2.22	11	100 ann'ld	+ .0025	4
"	pure, drawn	20	2.44	9	500 "	+ .0035	4
"	99.9 pure	194.5	3.77	17	1000 "	+ .0049	4
Ia Ia	see constantan	—	—	—	—	—	—
Ideal	" "	—	—	—	—	—	—
Indium	—	0	8.37	19	—	—	—
Iridium	—	−186	1.92	20	—	—	—
"	—	0	6.10	20	—	—	—
"	—	+100	8.3	20	—	—	—

Arranged in Order of Increasing Resistivity (ohm-cm³ × 10⁻⁶, 20°C)

Ag	1.468	Mn	5.±	Pd	10.21	Ga	53
Cu	1.59	Mo	(5.3)	Pt	10.96	Os	56
Au	2.22	Zn	5.75	Rb	13	Hg	94.07
Al	2.6	Ir	6.10	Sn	13	Bi	110
Cr	2.6	K	6.1	Ta	14.6	Graphite	8×10^2
Ti	3.2	Ni	6.93	Tl	17.6	Carbon	3×10^3
Na	4.3	Cd	7.04	Cs	19	Te	2×10^5
Ca	4.3	In	8.37	Pb	20.4	P	10^{12}
Mg	4.35	Li	8.55	Sr	(23.5)	B	8×10^{12}
Rh	4.69	Fe	8.8	As	35	Se	10^{13}
W	5	Co	9	Sb	39	S	10^{17}

TABLE 484 (*continued*)

RESISTIVITY OF METALS AND SOME ALLOYS

Substance	Remarks	Temperature °C	Microhm-cm	Reference	Temperature coefficient t_s	a_s	Reference
Iron	99.98% pure	20	10	5	20	+0.0050	5
"	pure, soft	−205.3	.652	17	0	+ .0062	21
"	" "	− 78	5.32	17	25	+ .0052	4
"	" "	0	8.85	17	100	+ .0068	4
"	" "	+ 98.5	17.8	17	500	+ .0147	4
"	" "	196.1	21.5	17	1000	+ .0050	4
"	" "	400	43.3	3	—	—	—
"	electrolytic	0	10.0	34	—	—	—
"	"	100	14.41	34	—	—	—
steel	E. B. B.	20	10.4	5	20 see col. 2	+ .005	5
"	B. B.	20	11.9	5	" " " "	+ .004	5
"	Siemens-Martin	20	18	5	" " " "	+ .003	5
"	manganese	20	70	5	" " " "	+ .001	5
"	35% Ni, "invar."	20	81	22	—	—	—
"	piano wire	0	11.8	23	0 see col. 2	+ .0032	23
"	temp. glass, hard	0	45.7	23	" " " "	+ .0016	23
"	" , yellow	0	27	23	—	—	—
"	" , blue	0	20.5	23	0 see col. 2	+ .0033	23
"	" , soft	0	15.9	23	—	—	—
Lead	—	20	22	5	20	+ .0039	5
"	cold pressed	−183	6.02	17	18	+ .0043	2
"	" "	− 78	14.1	17	—	—	—
"	" "	0	19.8	33	—	—	—
"	" "	+ 90.4	28	17	—	—	—
"	" "	196.1	36.9	17	—	—	—
"	—	318	94	24	—	—	—
Lithium	solid	−187	1.34	12	—	—	—
"	"	0	8.55	12	—	—	—
"	"	99.3	12.7	12	—	—	—
"	liquid	230	45.2	25	—	—	—
Magnesium	—	20	4.6	5	20	+ .004	5
"	free from Zn	−183	1.00	17	0	+ .0038	24
"	" " "	− 78	2.97	17	25	+ .0050	4
"	" " "	0	4.35	17	100	+ .0045	4
"	" " "	+ 98.5	5.99	17	500	+ .0036	4
"	pure	400	11.9	3	600	+ .0100	4
Manganese	—	—	5.0±	15	—	—	—
Manganin	84 Cu, 12 Mn, 4 Ni	20	44	5	12	+ .000006	4
"	—	—	—	—	25	.000000	4
"	—	—	—	—	100	− .000042	4
"	—	—	—	—	250	− .000052	4
"	—	—	—	—	475	− .000000	4
"	—	—	—	—	500	− .00011	4
Mercury	—	20	95.783	5	20	+ .00089	5
"	solid	−183.5	6.97	17	0	+ .00088	26
"	"	−102.0	15.04	17	—	—	—
"	"	− 50.3	21.3	17	$R_t = R_0(1 +$	—	—
"	"	− 39.2	25.5	17	$.00089t +$	—	—
"	liquid	− 36.1	80.6	17	$.000001t^2)$	—	—
"	"	0	94.07	17	—	—	—
"	"	50	98.50	27	—	—	—
"	"	100	103.25	24	—	—	—
"	"	200	114.27	24	—	—	—
"	"	350	135.5	24	—	—	—
Molybdenum	very pure	0	5.14	35	25	+ .0033	4
"	—	—	—	—	100	+ .0034	4
"	—	—	—	—	1000	+ .0048	4
Monel metal	—	20	42	5	20	+ .0020	5
Nichrome	—	20	100	5	20	+ .0004	5
Nickel	—	20	7.8	5	20	+ .006	5
"	very pure	20	7.236	31	—	—	—
"	pure	−182.5	1.44	28	0	+ .0062	24
"	"	− 78.2	4.31	28	25	+ .0043	4
"	"	0	6.93	28	100	+ .0043	4
"	"	94.9	11.1	28	500	+ .0030	4
"	—	—	—	—	1000	+ .0037	4

RESISTIVITY OF METALS AND SOME ALLOYS

Substance	Remarks	Temperature, °C	Microhm cm	Reference	Temperature coefficient t_0	a_0	Reference
Osmium	—	20	9.5	36	—	—	—
Palladium	—	20	11	5	20	+.0033	5
"	very pure	−183	2.78	17	0	+.0035	21
"	" "	− 78	7.17	17	—	—	—
"	" "	0	10.21	17	—	—	—
"	" "	98.5	13.79	17	—	—	—
Platinum	—	0	9.83	31	20	+.003	5
"	wire	−203.1	2.44	17	0	+.0037	21
"	"	− 97.5	6.87	17	—	—	—
"	"	0	10.96	17	—	—	—
"	"	100	14.85	17	—	—	—
"	—	400	26	3	—	—	—
Potassium	—	− 75	4	13	0	+.0057	33
"	—	0	6.1	13	—	—	—
"	—	55	8.4	13	—	—	—
Rhodium	—	−186	.70	20	—	—	—
"	—	− 78.3	3.09	20	—	—	—
"	—	0	5.11	33	0	+.0043	33
"	—	100	6.60	20	—	—	—
Rubidium	solid	−190	2.5	13	—	—	—
"	"	0	11.6	13	—	—	—
"	"	35	13.4	13	—	—	—
"	liquid	40	19.6	13	—	—	—
Silicium	—	20	58±	—	—	—	—
Silver	99.98 pure	18	1.629	2	20	+.0038	5
"	electrolytic	−183	.390	17	25	+.0030	4
"	"	− 78	1.021	17	100	+.0036	4
"	"	0	1.468	17	500	+.0044	4
"	"	98.15	2.062	17	—	—	—
"	"	192.1	2.608	17	—	—	—
"	"	400	3.77	3	—	—	—
Sodium	solid	−180	1.0	13	—	—	—
"	"	− 75	2.8	13	—	—	—
"	"	0	4.3	13	0	+.0054	3
"	"	55	5.4	13	—	—	—
"	liquid	116	10.2	13	—	—	—
Strontium	—	20	24.8	8	—	—	—
Tantalum	—	20	15.5	5	20	+.0031	5
Tellurium*	—	19.6	200,000	8	—	—	—
Thallium	pure	−183	4.08	17	—	—	—
"	"	− 78	11.8	17	—	—	—
"	"	0	17.60	17	—	—	—
"	"	98.5	24.7	17	—	—	—
Therlo	—	20	47	5	20	+.00001	5
Tin	—	20	11.5	5	20	+.0042	5
"	—	−184	3.40	17	—	—	—
"	—	− 78	8.8	17	—	—	—
"	—	0	13	17	—	—	—
"	—	91.45	18.2	17	—	—	—
Titanium	—	—	3.2	15	—	—	—
Tungsten	—	20	5.51	29	18	+.0045	2
"	1000°K	727	25.3	29	500	+.0057	4
"	1500°K	1227	41.4	29	1000	+.0089	4
"	2000°K	1727	59.4	29	—	—	—
"	3000°K	2727	98.9	29	—	—	—
"	3500°K	3227	118	29	—	—	—
Zinc	trace Fe	−183	1.62	17	20	+.0037	5
"	" "	− 78	3.34	17	—	—	—
"	" "	0	5.75	17	—	—	—
"	" "	92.45	8	17	—	—	—
"	" "	191.5	10.37	17	—	—	—
"	liquid	440	37.2	7	—	—	—

References to Table 484: (1) See page 421. (2) Jäger, Diesselhorst, Wiss. Abh. D. Phys. Tech. Reich. 3, p. 269, 1900. (3) Nicolai, 1907. (4) Somerville, Phys. Rev. 31, p. 261, 1910; 33, p. 77, 1911. (5) Circular 74, Bureau of Standards, 1918. (6) Eucken, Gehlhoff. (7) De la Rive. (8) Matthiessen. (9) Jäger, Diesselhorst. (10) Lees, 1908. (11) Mean. (12) Guntz, Broniewski. (13) Hackspill. (14) Swisher, 1917. (15) Shukow. (16) Reichardt, 1901. (17) Dewar, Fleming, Dickson, 1898. (18) Wolff, Dellinger, 1910. (19) Erhardt, 1881. (20) Broniewski, Hackspill, 1911. (21) Dewar, Fleming, 1893, 1896. (22) Circular 58, Bureau of Standards, 1916. (23) Strouhal, Barus, 1883. (24) Vincentini, Omodei, 1890. (25) Bernini, 1905. (26) Glazebrook, Phil. Mag. 20, p. 343, 1885. (27) Grimaldi, 1888. (28) Fleming, 1900. (29) Langmuir, Gen. Elec. Rev. 19, 1916. (30) Eucken-Gehlhoff, 1912. (31) Wenner-Lindberg, I. C. T., 1929. (32) Bidwell, 1922. (33) Mean. (34) Gumlich. (35) Worthing, I. C. T., 1929. (36) Blau, 1905.

* See note to Table 467.

TABLE 485.—Resistance of Metals under Pressure (Bridgman)

The average temperature coefficients are per ° C between 0° and 100° C. The instantaneous pressure coefficients are the values of the derivative $(1/r)\{dr/dp\}_t$, where r is the observed resistance at the pressure p and temperature t. The average coefficient is the total change of resistance between 0 and 12,000 kg/cm² divided by 12,000 and the resistance at atmospheric pressure and the temperature in question. Table taken from Proc. Nat. Acad. 3, p. 11, 1917. For coefficients at intermediate temperatures and pressures, see more detailed account in Proc. Amer. Acad. 52, p. 573, 1917. Sn, Cd, Zn, Kahlbaum's "K" grade; Tl, Bi, electrolytic, high purity; Pb, Ag, Au, Cu, Fe, Pt, of exceptional purity. Al better than ordinary, others only of high grade commercial purity.

	Average temperature coefficient 0° to 100° C		Pressure coefficients.					
			Instantaneous coefficient.				Average coefficient 0 to 12,000 kg/cm²	
			At 0° C		At 100° C			
	At 0 kg	At 12,000 kg	0 kg	12,000 kg	0 kg	12,000 kg	At 0°	At 100°
In	+.00406	+.00383	$-.0_41226$	$-.0_41016$	$-.0_41510$‡	$-.0_41072$‡	$-.0_41021$	$-.0_41131$ ‡
Sn	.00447	.00441	$.0_41044$	$.0_40936$	$.0_41062$	$.0_40973$	$.0_40920$	$.0_40951$
Tl	.00517	.00499	$.0_41319$	$.0_41180$	$.0_41456$	$.0_41200$	$.0_41151$	$.0_41226$
Cd	.00424	.00418	$.0_41063$	$.0_40837$	$.0_41106$	$.0_40887$	$.0_40894$	$.0_40927$
Pb	.00421	.00412	$.0_41442$	$.0_41220$	$.0_41483$	$.0_41237$	$.0_41212$	$.0_41253$
Zn	.00416	.00420	$.0_40540$	$.0_40425$	$.0_40524$	$.0_40407$	$.0_40470$	$.0_40454$
Al	.00434	.00435	$.0_40416$	$.0_40365$	$.0_40397$	$.0_40373$	$.0_40382$	$.0_40377$
Ag	.004074	.004069	$.0_40358$	$.0_40321$	$.0_40355$	$.0_40331$	$.0_40333$	$.0_40336$
Au	.003968	.003964	$.0_40312$	$.0_40286$	$.0_40304$	$.0_40292$	$.0_40287$	$.0_40292$
Cu	.004293	.004303	$.0_40201$	$.0_40179$	$.0_40184$	$.0_40175$	$.0_40183$	$.0_40177$
Ni	.004873	.004855	$.0_40158$	$.0_40142$	$.0_40163$	$.0_40156$	$.0_40147$	$.0_40158$
Co	.003657	.003676	$.0_40094$	$.0_40081$	$.0_40076$	$.0_40070$	$.0_40087$	$.0_40073$
Fe	.006206	.006184	$.0_40241$	$.0_40218$	$.0_40247$	$.0_40230$	$.0_40226$	$.0_40235$
Pd	.003178	.003185	$.0_40198$	$.0_40190$	$.0_40189$	$.0_40187$	$.0_40190$	$.0_40186$
Pt	.003868	.003873	$.0_40198$	$.0_40181$	$.0_40190$	$.0_40182$	$.0_40187$	$.0_40184$
Mo	.004336	.004340	$.0_40133$	$.0_40126$	$.0_40130$	$.0_40125$	$.0_40129$	$.0_40126$
Ta	.002973	.002967	$.0_40149$	$.0_40139$	$.0_40153$	$.0_40147$	$.0_40143$	$.0_40149$
W	.003219	.003216	$.0_40128$	$.0_40121$	$.0_40130$	$.0_40123$	$.0_40123$	$.0_40126$
Mg	.00390 *	—	$.0_455$	—	—	—	$.0_455$	—
Sb	.00473	.00403	$+.0_41220$	$+.0_41064$	$+.0_40768$	$+.0_40723$	$+.0_41220$	$+.0_40768$
Bi	+.00438	+.00395	$+.0_4154$	$+.0_40213$	$+.0_4152$ §	$+.0_41895$§	$+.0_42228$	$+.0_41980$ §
Te	−.0063 †	—	$-.0_3129$	—	—	—	—	—

* 0° to 20°. † 0° to 24°. ‡ Extrapolated from 50°. § Extrapolated from 75°.

Additional data from P. Nat. Acad. Sc., 6, 505, 1920. Data are 10,000 × mean pressure coefficient, 0 − 12,000 kg, and 10,000 × instantaneous pressure coefficient at 0 kg. l = liquid; s = solid.

Li, s, 0°	+.0772	+ .068	Ca, 0°	+.106	+.129	Ti, 0°	±.001?	
Li, l, 240°	+.093	+ .093	Sr, 0°	+.680	+.502	Zr, 0°	−.0040	−.004
Na, s, 0°	−.345	− .663	Hg, s, 0°	−.236b		Bi, l, 275°	−.101c	−.123
Na, l, 200°	−.436	− .922	Hg, l, 25°	−.219	−.334	W, 0°	−.0135	−.014
K, s, 25°	−.604	− 1.86	Ga, s, 0°	−.0247		La, 0°	−.0331	−.039
K, l, 165°	−.809a	− 1.68	Ga, l, 30°	−.0531	−.064	P, black, 0°	−.81	− 2.00

a, 0 − 9,000 kg; b, 7,640 − 12,000 kg; c, 0 − 7,000 kg. The Ga, Na, K, Mg, Hg, Bi, W, P, of exceptional purity.

TABLE 486.—Resistance of Mercury and Manganin under Pressure

Mercury, pure and free from air and with proper precautions, makes a reliable secondary electric-resistance pressure gauge. For construction and manipulation see "The Measurement of High Hydrostatic Pressure; a Secondary Mercury Resistance Gauge," Bridgman, Pr. Am. Acad. 44, p. 221, 1919.

Pressure, kg/cm²	—	500	1000	1500	2000	2500	3000	4000	5000	6000	6500
$R(p, -75°)$	0.9186	0.9055	0.8930	0.8818	0.8714	0.8582	0.8478	0.8268	0.8076	0.7896	0.7807
$R(p, 25°)$	1.0000	0.9836	0.9682	0.9535	0.9394	0.9258	0.9128	0.8882	0.8652	0.8438	0.8335
*	1.0000	0.9854	0.9716	0.9588	0.9462	0.9342	0.9228	0.9010	0.8806	0.8616	0.8527
$R(p, 125°)$	1.0970	1.0770	1.0580	1.0400	1.0230	1.0070	0.9908	0.9614	0.9342	0.9086	0.8966

* This line gives the Specific Mass Resistance at 25°, the other lines the specific volume resistance.

The use of mercury as above has the advantage of being perfectly reproducible so that at any time a pressure can be measured without recourse to a fundamental standard. However, at 0° C mercury freezes at 7500 kg/cm². Manganin is suitable over a much wider range. Over a temperature range 0 to 50° C the pressure resistance relation is linear within 1/10 per cent of the change of resistance up to 13,000 kg/cm². The coefficient varies slightly with the sample. Bridgman's samples (German) had values of $(\Delta R/pR_0) \times 10^9$ from 2295 to 2325. These are + instead of −, as with most of the above metals. See "The Measurement of Hydrostatic Pressure up to 20,000 Kilograms per Square Centimeter," Bridgman, Pr. Am. Acad. 47, p. 321, 1911.

EFFECT OF TENSION ON THE RESISTANCE OF METALS

(Bridgman, Proc. Amer. Acad. Arts and Sci., 57, 41, 1922.)

Generally hydrostatic pressure decreases the electrical resistance of metals. A few are abnormal (see Table 485)—Bi, Li, Ca, Sr, Sb. Unit stress, kg/cm². The tension coefficient of specific resistance is obtained by subtracting $(1 + 2\sigma)/E$ from the coefficient of observed resistance.

	Li	Ca	Sr	Sb	Bi	Mang.	Therlo	Co
Recip. Young's mod. $\times 10^6$....	20	4.75	7.5	1.25	4.2	0.72	0.69	0.5
Poisson ratio....	.42	.30	.36	.30?	.37	.33	.33	.30
Tens. coef. spec. resist. $\times 10^6$...	+11	+ .8	−21.2	+3.0	−3.65	− .60	− .73	+ .19

Supplementary Values to Table 484

Resistance temperature coefficient for a number of metals and alloys of high purity due to J. R. Caldwell (1931).

Metal	$(R_{100}-R_0)/100R_0$	Alloy	$(R_{100}-R_0)/100R_0$
Ni	0.00667	95 Pt— 5 Rh	0.00215
Zn	.00419	90 Pt—10 Rh	0.00169
Cd	.00423	80 Pt—20 Rh	0.00140
Pt	.003925	60 Pt—40 Rh	0.00144
Rh	.00436	40 Pt—60 Rh	0.00194
		20 Pt—80 Rh	0.00260

Note to Table 491, p. 417: Superconductivity. Apparent only below about 10° K. (−263° C). The following metals are known to show it below the indicated temperatures. A low current density is necessary.

Titanium	1°75 K.	Indium	3°37 K.	Thallium	2°37 K.
Gallium	1.05	Tin	3.7	Lead	7.2
Niobium	8.2	Tantalum	4.4	Thorium	1.5
Molybdenum	1.?	Mercury	4.22	Some alloys	

Zn, Cd, Ge, Al, Pt, Na, Li do not show it.
McLennan, Nature, 130, Dec. 10, 1932. Hill, Rev. Scientific Instr., 4, 3, 1933.

TABLE 488

CONDUCTIVITY AND RESISTIVITY OF MISCELLANEOUS ALLOYS

TEMPERATURE COEFFICIENTS

Conductivity in mhos or $\frac{1}{\text{ohms per cm}^3} = \gamma_t = \gamma_0(1 - at + bt^2)$ and resistivity in microhms – cm $= \rho_t = \rho_0(1 + at - b^2)$.

Metals and alloys	Composition by weight	$\frac{\gamma_0}{10^4}$	$a \times 10^6$	ρ_0	Authority
Gold-copper-silver	58.3 Au + 26.5 Cu + 15.2 Ag	7.58	574*	13.2	1
" " "	66.5 Au + 15.4 Cu + 18.1 Ag	6.83	529†	14.6	1
" " "	7.4 Au + 78.3 Cu + 14.3 Ag	28.06	1830‡	3.6	1
Invar	....	1.33	2000	75	10
Welding iron	0.05% Cu	6.25	6000	18	9
Woods metal	56Bi,17Cd,14Pb,13Sn	1.93	2900	52	11
Brass	Various	12.2–15.6	1–2 × 10³	6.4–8.4	2
" hard drawn	70.2 Cu + 29.8Zn	12.16	—	8.2	3
" annealed	" "	14.35	—	7.0	3
German silver	Various	3–5	—	20–33	2
" "	60.16 Cu + 25.37 Zn + 14.03 Ni + .30 Fe with trace of cobalt and manganese	3.33	360	30	4
Aluminum bronze	....	7.5–8.5	600	12–13	2
Phosphor bronze	....	10–20	—	5–10	2
Silicium bronze	....	41	—	2.4	5
Manganese-copper	30 Mn + 70 Cu	1.00	40	100	4
Nickel-manganese-copper	3 Ni + 24 Mn + 73 Cu	2.10	—30	48	4
Nickelin	18.46 Ni + 61.63 Cu + 19.67 Zn + 0.24 Fe + 0.19 Co + 0.18 Mn	3.01	300	33	4
Patent nickel	25.1 Ni + 74.41 Cu + 0.42 Fe + 0.23 Zn + 0.13 Mn + trace of cobalt	2.92	190	34	4
Rheotan	53.28 Cu + 25.31 Ni + 16.89 Zn + 4.46 Fe + 0.37 Mn	1.90	410	53	4
Rheotan	53 Cu,25Ni,17Zn,5Fe	2.24	280	45	12
Copper-manganese-iron	91 Cu + 7.1 Mn + 1.9 Fe	4.98	120	20	6
Copper-manganese-iron	70.6 Cu + 23.2 Mn + 6.2 Fe	1.30	22	77	6
Copper-manganese-iron	69.7 Cu + 29.9 Ni + 0.3 Fe	2.60	120	38	7
Therlo	85 Cu,13Mn,2Al	2.24	10	46.5	10
Manganin	84 Cu + 12 Mn + 4 Ni	2.3	6	44	2
Constantan	60 Cu + 40 Ni	2.04	8	49	8

1 Matthiessen. 2 Various. 3 W. Siemens. 4 Feussner and Lindeck. 5 Van der Ven. 6 Blood. 7 Feussner. 8 Jaeger-Diesselhorst. 9 LeChatelier. 10 I.C.T. 11 Weber. 12 Niccolai.

*, †, ‡, $b \times 10^9$ = 924, 93, 7280.

Table 489

CONDUCTING POWER OF ALLOYS

This table shows the conducting power of alloys and the variation of the conducting power with temperature.* The values of C_0 were obtained from the original results by assuming silver $= \frac{10^6}{1.585}$ mhos. The conductivity is taken as $C_t = C_0 (1 - at + bt^2)$, and the range of temperature was from 0° to 100° C.

The table is arranged in three groups to show (1) that certain metals when melted together produce a solution which has a conductivity equal to the mean of the conductivities of the components, (2) the behavior of those metals alloyed with others, and (3) the behavior of the other metals alloyed together.

It is pointed out that, with a few exceptions, the percentage variation between 0° and 100° can be calculated from the formula $P = P_c \frac{l}{l'}$, where l is the observed and l' the calculated conducting power of the mixture at 100° C and P_c is the calculated mean variation of the metals mixed.

Alloys.	Weight % of first named.	Volume % of first named.	$\frac{C_0}{10^4}$	$a \times 10^6$	$b \times 10^9$	Variation per 100° C. Observed.	Variation per 100° C. Calculated.
Group 1.							
Sn_6Pb	77.04	83.96	7.57	3890	8670	30.18	29.67
Sn_4Cd	82.41	83.10	9.18	4080	11870	28.89	30.03
SnZn	78.06	77.71	10.56	3880	8720	30.12	30.16
PbSn	64.13	53.41	6.40	3780	8420	29.41	29.10
$ZnCd_2$	24.76	26.06	16.16	3780	8000	29.86	29.67
$SnCd_4$	23.05	23.50	13.67	3850	9410	29.08	30.25
$CdPb_6$	7.37	10.57	5.78	3500	7270	27.74	27.60
Group 2.							
Lead-silver ($Pb_{20}Ag$)	95.05	94.64	5.60	3630	7960	28.24	19.96
Lead-silver (PbAg)	48.97	46.90	8.03	1960	3100	16.53	7.73
Lead-silver ($PbAg_2$)	32.44	30.64	13.80	1990	2600	17.36	10.42
Tin-gold ($Sn_{12}Au$)	77.94	90.32	5.20	3080	6640	24.20	14.83
" " (Sn_5Au)	59.54	79.54	3.03	2920	6300	22.90	5.95
Tin-copper	92.24	93.57	7.59	3680	8130	28.71	19.76
" " †	80.58	83.60	8.05	3330	6840	26.24	14.57
" " †	12.49	14.91	5.57	547	294	5.18	3.99
" " †	10.30	12.35	6.41	666	1185	5.48	4.46
" " †	9.67	11.61	7.64	691	304	6.60	5.22
" " †	4.96	6.02	12.44	995	705	9.25	7.83
" " †	1.15	1.41	39.41	2670	5070	21.74	20.53
Tin-silver	91.30	96.52	7.81	3820	8190	30.00	23.31
" "	53.85	75.51	8.65	3770	8550	29.18	11.89
Zinc-copper †	36.70	42.06	13.75	1370	1340	12.40	11.29
" " †	25.00	29.45	13.70	1270	1240	11.49	10.08
" " †	16.53	23.61	13.44	1880	1800	12.80	12.30
" " †	8.89	10.88	29.61	2040	3030	17.41	17.42
" " †	4.06	5.03	38.09	2470	4100	20.61	20.62

Note. — Barus, in the "Am. Jour. of Sci." vol. 36, has pointed out that the temperature variation of platinum alloys containing less than 10% of the other metal can be nearly expressed by an equation $y = \frac{n}{x} - m$, where y is the temperature coefficient and x the specific resistance, m and n being constants. If α be the temperature coefficient at 0° C and s the corresponding specific resistance, $s(\alpha + m) = n$.

For platinum alloys Barus's experiments gave $m = -.000194$ and $n = .0378$.
For steel $m = -.000303$ and $n = .0620$.

Matthiessen's experiments reduced by Barus gave for

Gold alloys $m = -.000045$, $n = .00721$.
Silver " $m = -.000112$, $n = .00538$.
Copper " $m = -.000386$, $n = .00055$.

* From the experiments of Matthiessen and Vogt, "Phil. Trans. R. S." v. 154.
† Hard-drawn.

TABLE 489 (*continued*).—Conducting Power of Alloys

GROUP 3.

Alloys.	Weight % of first named.	Volume % of first named.	$\frac{C_0}{10^4}$	$a \times 10^6$	$b \times 10^9$	Variation per 100° C. Observed.	Variation per 100° C. Calculated.
Gold-copper † . . .	99.23	98.36	35.42	2650	4650	21.87	23.22
" " † . . .	90.55	81.66	10.16	749	81	7.41	7.53
Gold-silver †	87.95	79.86	13.46	1090	793	10.09	9.65
" " *	87.95	79.86	13.61	1140	1160	10.21	9.59
" " †	64.80	52.08	9.48	673	246	6.49	6.58
" " *	64.80	52.08	9.51	721	495	6.71	6.42
" " †	31.33	19.86	13.69	885	531	8.23	8.62
" " *	31.33	19.86	13.73	908	641	8.44	8.31
Gold-copper † . . .	34.83	19.17	12.94	864	570	8.07	8.18
" " † . . .	1.52	0.71	53.02	3320	7300	25.90	25.86
Platinum-silver † . .	33.33	19.65	4.22	330	208	3.10	3.21
" " † . .	9.81	5.05	11.38	774	656	7.08	7.25
" " † . .	5.00	2.51	19.96	1240	1150	11.29	11.88
Palladium-silver † . .	25.00	23.28	5.38	324	154	3.40	4.21
Copper-silver † . . .	98.08	98.35	56.49	3450	7990	26.50	27.30
" " † . . .	94.40	95.17	51.93	3250	6940	25.57	25.41
" " † . . .	76.74	77.64	44.06	3030	6070	24.29	21.92
" " † . . .	42.75	46.67	47.29	2870	5280	22.75	24.00
" " † . . .	7.14	8.25	50.65	2750	4360	23.17	25.57
" " † . . .	1.31	1.53	50.30	4120	8740	26.51	29.77
Iron-gold †	13.59	27.93	1.73	3490	7010	27.92	14.70
" " †	9.80	21.18	1.26	2970	1220	17.55	11.20
" " †	4.76	10.96	1.46	487	103	3.84	13.40
Iron-copper † . . .	0.40	0.46	24.51	1550	2090	13.44	14.03
Phosphorus-copper † .	2.50	–	4.62	476	145	–	–
" " † .	0.95	–	14.91	1320	1640	–	–
Arsenic-copper † . .	5.40	–	3.97	516	989	–	–
" " † . .	2.80	–	8.12	736	446	–	–
" " † . .	trace	–	38.52	2640	4830	–	–

* Annealed. † Hard-drawn.

TABLE 490.—Allowable Carrying Capacity of Rubber-covered Copper Wires

(For inside wiring — Nat. Board Fire Underwriters' Rules.)

B + S Gage	18	16	14	12	10	8	6	5	4	3	2	1	0	00	0000
Amperes	3	6	12	17	24	33	46	54	65	76	90	107	127	150	210

500,000 circ. mills, 390 amp.; 1,000,000 c. m., 650 amp.; 2,000,000 c. m., 1,050 amp. For insulated al. wire, capacity = 84% of cu. Preece gives as formula for fusion of bare wires $I = ad^{\frac{3}{2}}$, where d = diam. in inches, a for cu. is 10,244; al., 7585; pt., 5172; German silver, 5230; platinoid, 4750; Fe, 3148; Pb., 1379; alloy 2 pts. Pb., 1 of Sn., 1318.

RESISTIVITIES AT HIGH AND LOW TEMPERATURES*

The electrical resistivity (ρ, ohms per cm. cube) of good conductors depends greatly on chemical purity. Slight contamination even with metals of lower ρ may greatly increase ρ. Solid solutions of good conductors generally have higher ρ than components. Reverse is true of bad conductors. In solid state allotropic and crystalline forms greatly modify ρ. For liquid metals this last cause of variability disappears. The + temperature coefficients of pure metals is of the same order as the coefficients of expansion of gases. For temperature resistance (t, ρ) plot at low temperatures the graph is convex towards the axis of t and probably approaches tangency to it. However for extremely low temperatures Onnes finds very sudden and great drops in ρ. *e.g.* for Mercury, $\rho_{3.6K} < 4\times10^{-10}\,\rho_0$ and for Sn., $\rho_{3.8K} < 10^{-7}\rho_0$. The t, ρ graph for an alloy may be nearly parallel to the t axis, cf. constantan; for poor conductors ρ may decrease with increasing t. At the melting-points there are three types of behavior of good conductors: those about doubling ρ and then possessing nearly linear t, ρ graphs (Al., Cu., Sn., Au., Ag., Pb.); those where ρ suddenly increases and then the + temp. coefficient is only approximately constant; (Hg., Na., K.); those about doubling ρ then having a −, slowly changing to a + temp. coef. (Zn., Cd.); those where ρ suddenly decreases and thereafter steadily increases (Sb., Bi.). The values from different authorities do not necessarily fit because of different samples of metals. The Shimank values (t given to tenths of °) are for material of theoretical purity and are determined by the α rule (see his paper, also Nernst, Ann. d Phys. 36, p. 403, 1911 for temperature resistance thermometry). The Shimank and Pirrani values are originally given as ratios to ρ_0. (Ann. d. Phys. 45, p. 706, 1914, 46, p. 176, 1915.) Resistivities are in micro-ohms per cm. cube unless stated. Italicized figures indicate liquid state.

Gold.			Copper.			Silver.			Zinc.		
°C.	ρ_t	ρ_t/ρ_0	°C.	ρ_t	ρ_t/ρ_0	°C.	ρ_t	ρ_t/ρ_0	°C.	ρ_t	ρ_t/ρ_0
-252.8	0.018	.0081	-258.6	0.014	.0091	-258.6	0.009	.0057	-252.9	.0511	.0089
-200.	.601	.267	-252.8	.016	.0103	-252.8	.014	.0090	-200.	1.39	.242
-192.5	.520	.231	-251.1	.028	.0178	-189.5	.334	.222	-191.1	1.23	.214
-150.	.997	.444	-206.6	.163	.1035	-200.	.357	.237	-150.	2.00	.348
-100.	1.400	.623	-192.9	.249	.1580	-150.	.638	.424	-100.	2.90	.504
-77.6	1.564	.696	-150.	.567	.359	-100.	.916	.608	- 77.8	3.97	.691
-50.	1.813	.806	-100.	.904	.573	-76.8	1.040	.690	- 50.	4.04	.703
0.	2.247	1.00	-50.	1.240	.786	-50.	1.212	.805	0.	5.75	1.00
100.	2.97	1.32	0.	1.578	1.00	0.	1.506	1.00	100.	7.95	1.38
200.	3.83	1.70	100.	2.28	1.44	100.	2.15	1.43	300.	13.25	2.30
500.	6.62	2.94	200.	2.96	1.88	200.	2.80	1.86	415.	17.00	2.96
750.	9.35	4.16	500.	5.08	3.22	400.	3.46	2.30	427.	*37.30*	*6.49*
1000.	12.54	5.58	750.	7.03	4.46	750.	6.65	4.42	450.	*37.08*	*6.46*
1063.	13.50	6.01	1000.	9.42	5.97	960.	8.4	5.58	500.	*36.60*	*6.36*
1063.	*30.82*	*13.7*	1083.	10.20	6.47	960.	*16.6*	*11.0*	600.	*35.90*	*6.25*
1200.	*32.8*	*14.6*	1083.	*21.30*	*13.5*	1000.	*17.01*	*11.3*	700.	*35.60*	*6.19*
1400.	*35.6*	*15.8*	1200.	*22.30*	*14.1*	1200.	*19.36*	*12.9*	800.	*35.60*	*6.19*
1500.	*37.0*	*16.5*	1400.	*23.86*	*15.1*	1400.	*21.72*	*14.4*	850.	*35.74*	*6.21*
			1500.	*24.62*	*15.6*	1500.	*23.0*	*15.3*			

Mercury.			Potassium.			Sodium.			Iron.		
°C.	ρ_t	ρ_t/ρ_0	°C	ρ_t	ρ_t/ρ_0	°C.	ρ_t	ρ_t/ρ_0	°C.	ρ_t	ρ_t/ρ_0
-200.	5.38	057	-200.	1.720	.246	-200.	0.605	.137	-252.7	0.011	.0010
-150.	10.30	.109	-150.	2.654	.379	-150.	1.455	.330	-200.	2.27	.212
-100.	15.42	.164	-100.	3.724	.532	-100.	2.380	.541	-192.5	.844	.079
-50.	21.4	.227	-50.	5.124	.732	-50.	3.365	.764	-100.	5.92	.554
-30.	*91.7*	*.975*	0.	7.000	1.00	0.	4.40	1.000	- 75.1	6.43	.602
0.	*94.1*	*1.000*	20.	7.116	1.016	20.	4.873	1 107	- 50.	8.15	.763
50.	*98.3*	*1.045*	60.	8.790	1.256	93.5	6.290	1.429	- 0.	10.68	1.00
100.	*103.1*	*1.096*	65.	*13.40*	*1.914*	100.	*9.220*	*2.095*	100.	16.61	1.554
200.	*114.0*	*1.212*	100.	*15.31*	*2.187*	120.	*9.724*	*2.209*	200.	24.50	2.293
300.	*127.0*	*1.350*	120.	*16.70*	*2.386*	140.	*10.34*	*2.349*	400.	43.29	4.052

Manganin.			German Silver.			Constantan.			90 % Pt. 10 % Rh.		
°C.	ρ_t	ρ_t/ρ_0	°C.	ρ_t	ρ_t/ρ_0	°C.	ρ_t	ρ_t/ρ_0	°C.	ρ_t	ρ_t/ρ_0
-200.	37.8	.974	-200.	27.9	.930	-200.	42.4	.961	-200.	14.49	.685
-150.	38.2	.985	-150.	28.7	.957	-150.	43.0	.975	-150.	16.29	.770
-100.	38.5	.992	-100.	29.3	.977	-100.	43.5	.986	-100.	18.05	.854
-50.	38.7	.997	-50.	29.7	.990	-50.	43.9	.995	- 50.	19.66	.930
0.	38.8	1.000	0.	30.0	1.000	0.	44.1	1.000	0.	21.14	1.000
100.	38.9	1.003	100.	33.1	1.103	100.	44.6	1.012	100.	24.20	1.145
400.	38.3	.987				400.	44.8	1.016			

Au. below 0°, Niccolai, Lincei Rend. (5), 16, p. 757, 906, 1907; above, Northrup, Jour. Franklin Inst. 177, p. 85, 1914. Cu. below, Niccolai, l. c. above, Northrup, ditto, 177. p. 1, 1914. Ag. below, Niccolai, l. c. above Northrup, ditto, 178, p. 85, 1914. Zn. below, Dewar, Fleming, Phil. Mag. 36, p. 271, 1893; above, Northrup, 175, p. 153, 1913. Hg. below Dewar, Fleming, Proc. Roy. Soc. 66, p. 76, 1900; above, Northrup, see Cd. K. below Guntz, Broniewski, C. R. 147, p. 1474, 1908, 148, p. 204, 1909. Above, Northrup, Tr. Am. Electroch. Soc. p. 185, 1911. Na, below, means, above, see K. Fe., Manganin, Constantan. Niccolai, l.c. German Silver, 90% Pt. 90% Rh., Dewar and Fleming — Phil. Mag. 36, p. 271, 1893. * See also page 413.

TABLE 491 (*continued*).—Resistivities at High and Low Temperatures

(Ohms per cm cube unless stated otherwise.)

Platinum.			Lead.			Bismuth.			Cadmium.		
°C.	ρ_t	$\frac{\rho_t}{\rho_0}$	°C.	ρ_t	$\frac{\rho_t}{\rho_0}$	°C.	ρ_t	$\frac{\rho_t}{\rho_0}$	°C.	ρ_t	$\frac{\rho_t}{\rho_0}$
−265.	0.10	.0092	−252.9	0.59	.0298	−200.	34.8	.314	−252.9	0.17	.0218
−253.	.15	.014	−203.	4.42	.223	−150.	55.3	.499	−200.	1.66	.214
−233.	.54	.049	−192.8	5.22	.264	−100.	75.6	.683	−190.2	2.00	.258
−153.	4.18	.378	−103.	11.8	.598	− 50.	94.3	.852	−183.1	2.22	.286
− 73.	7.82	.708	− 75.8	13.95	.705	0.	110.7	1.00	−139.2	3.60	.464
0.	11.05	1.00	− 53.	15.7	.792	17.	120.0	1.083	−100.	4.80	.619
100.	14.1	1.28	0.	19.8	1.00	100.	156.5	1.413	0.	7.75	1.00
200.	17.9	1.62	100.	27.8	1.403	200.	214.5	1.937	300.	16.50	2.13
400.	25.4	2.30	200.	38.0	1.919	259.	267.0	2.411	325.	*33.76*	*4.35*
800.	40.3	3.65	319.	50.0	2.52	263.	*127.5*	*1.150*	350.	*33.60*	*4.33*
1000.	47.0	4.25	333.	*95.0*	*4.80*	300.	*128.9*	*1.164*	400.	*33.70*	*4.35*
1200.	52.7	4.77	400.	*98.3*	*4.96*	500.	*139.9*	*1.263*	500.	*35.12*	*4.40*
1400.	58.0	5.25	600.	*107.2*	*5.41*	700.	*150.8*	*1.361*	700.	*35.78*	*4.62*
1600.	63.0	5.70	800.	*116.2*	*5.86*	750.	*153.5*	*1.386*			

Tin.			Carbon, Graphite.*			Fused silica.		Alundum cement.	
°C.	ρ_t	$\frac{\rho_t}{\rho_0}$	°C.	ρ in ohms, cm. cube.		°C.	ρ = megohms cm.	°C.	ρ in ohms cm. cube.
−200.	2.60	.199		Carbon	Graphite	15.	>200,000,000.	20.	>9 × 10⁶
−100.	7.57	.580	0.	0.0035	0.00080	230.	20,000,000.	800.	30800.
0.	13.05	1.00	500.	.0027	.00083	300.	200,000.	900.	13600.
200.	20.30	1.55	1000.	.0021	.00087	350.	30,000.	1000.	7600.
225.	22.00	1.69	1500.	.0015	.00090	450.	800.	1100.	6500.
235.	*47.60*	*3.05*	2000.	.0011	.00100	700.	30.	1200.	2300.
750.	*61.22*	*4.69*	2500.	.0009	.0011	850.	about 20.	1600.	190.

Pt. low, Nernst, l. c. high, Pirrani, Ber. Deutsch. Phys. Ges. 12, p. 305, Pb. low, Schimank, Nernst, l. c. high. Northrup, see Zn. Bi. low, means, high, Northrup, see Zn. Cd. low, Euchen, Gehlhoff, Verh. Deutsch. Phys. Ges. 14, p. 169, 1912, high, Northrup, see Zn. Sn. low, Dewar, Fleming, high, Northrup, see Zn. Carbon, graphite, Metallurg. Ch. Eng. 13, p. 23, 1915. Silica, Campbell, Nat. Phys. Lab. 11, p. 207, 1914. Alundum, Metallurg. Ch. Eng. 12, p. 125, 1914.

* Diamond 1030° C, $\rho > 10^7$; 1380°, 7.5×10^5, v. Wartenberg, 1912.

TABLE 492.—Volume and Surface Resistivity of Solid Dielectrics

The resistance between two conductors insulated by a solid dielectric depends both upon the surface resistance and the volume resistance of the insulator. The volume resistivity, ρ, is the resistance between two opposite faces of a centimeter cube. The surface resistivity, σ, is the resistance between two opposite edges of a centimeter square of the surface. The surface resistivity usually varies through a wide range with the humidity. (Curtis, Bul. Bur. Standards, 11, 359, 1915, which see for discussion and data for many additional materials.)

Material.	σ; megohms 50% humidity.	σ; megohms 70% humidity.	σ; megohms 90% humidity.	ρ Megohms-cms.
Amber	6×10^8	2×10^8	1×10^5	5×10^{10}
Beeswax, yellow	6×10^8	6×10^8	5×10^8	2×10^9
Celluloid	5×10^4	2×10^4	2×10^3	2×10^4
Fiber, red	2×10^4	3×10^3	2×10^2	5×10^3
Glass, plate	5×10^4	6×10	2×10	2×10^7
" Kavalier	4×10^6	4×10^3	1×10^3	8×10^9
Hard rubber, new	3×10^9	1×10^8	2×10^3	1×10^{12}
Ivory	5×10^3	1×10^3	3×10	2×10^2
Khotinsky cement	7×10^8	3×10^8	5×10^5	2×10^9
Marble, Italian	3×10^3	2×10^2	2×10	1×10^5
Mica, colorless	2×10^7	4×10^5	8×10^3	2×10^{11}
Paraffin (parowax)	9×10^9	7×10^9	6×10^9	1×10^{10}
Porcelain, unglazed	6×10^5	7×10^3	5×10	3×10^8
Quartz, fused	3×10^6	2×10^3	2×10^2	5×10^{12}
Rosin	6×10^8	3×10^8	2×10^8	5×10^{10}
Sealing wax	2×10^9	6×10^8	9×10^7	8×10^9
Shellac	6×10^7	3×10^6	7×10^3	1×10^{10}
Slate	9×10	3×10	1×10	1×10^2
Sulphur	7×10^9	4×10^9	1×10^8	1×10^{11}
Wood, parafined mahogany	4×10^6	5×10^5	7×10^3	4×10^7

TABLE 493.—Variation of Electrical Resistance of Glass and Porcelain with Temperature

The following table gives the values of a, b, and c in the equation

$$\log R = a + bt + ct^2,$$

where R is the specific resistance expressed in ohms, that is, the resistance in ohms per centimeter of a rod one square centimeter in cross section.*

No.	Kind of glass.	Density.	a	b	c	Range of temp. Centigrade.
1	Test-tube glass	–	13.86	—.044	.000065	0°–250°
2	" " "	2.458	14.24	—.055	.0001	37–131
3	Bohemian glass	2.43	16.21	—.043	.0000394	60–174
4	Lime glass (Japanese manufacture)	2.55	13.14	—.031	—.000021	10–85
5	" " " "	2.499	14.002	—.025	—.00006	35–95
6	Soda-lime glass (French flask)	2.533	14.58	—.049	.000075	45–120
7	Potash-soda lime glass	2.58	16.34	—.0425	.0000364	66–193
8	Arsenic enamel flint glass	3.07	18.17	—.055	.000088	105–135
9	Flint glass (Thomson's electrometer jar)	3.172	18.021	—.036	—.0000091	100–200
10	Porcelain (white evaporating dish)	–	15.65	—.042	.00005	68–290

COMPOSITION OF SOME OF THE ABOVE SPECIMENS OF GLASS.

Number of specimen =	3	4	5	7	8	9
Silica	61.3	57.2	70.05	75.65	54.2	55.18
Potash	22.9	21.1	1.44	7.92	10.5	13.28
Soda	Lime, etc.	Lime, etc.	14.32	6.92	7.0	–
Lead oxide	by diff.	by diff.	2.70	–	23.9	31.01
Lime	15.8	16.7	10.33	8.48	0.3	0.35
Magnesia	–	–	–	0.36	0.2	0.06
Arsenic oxide	–	–	–	–	3.5	–
Alumina, iron oxide, etc.	–	–	1.45	0.70	0.4	0.67

* T. Gray, "Phil. Mag." 1880, and "Proc. Roy. Soc." 1882.

TABLE 494.—Temperature Resistance Coefficients of Glass, Porcelain and Quartz dr/dt

Temperature.	450°	500°	575°	600°	700°	750°	800°	900°	1000°
Glass	—32.	—6.	—1.5	—.8	—0.17	—0.1	—0.06	–	–
Porcelain	–	–	—16.	—9.8	—2.8	—1.6	—.70	—0.30	—0.12
Quartz	–	–	–	–	–	—10.	—6.40	—2.60	—1.00

Somerville, Physical Review, 31, p. 261, 1910.

Table 495

TABULAR COMPARISON OF WIRE GAGES

Gage No.	American wire gage (B. & S.) mils.†	American wire gage (B. & S.) mm.†	Steel wire gage* mils.	Steel wire gage* mm.	Stubs' steel wire gage mils.	(British) standard wire gage mils.	Birmingham wire gage (Stubs') mils.	Gage No.
7-0			490.0	12.4		500.		7-0
6-0			461.5	11.7		464.		6-0
5-0			430.5	10.9		432.		5-0
4-0	460.	11.7	393.8	10.0		400.	454.	4-0
3-0	410.	10.4	362.5	9.2		372.	425.	3-0
2-0	365.	9.3	331.0	8.4		348.	380.	2-0
0	325.	8.3	306.5	7.8		324.	340.	0
1	289.	7.3	283.0	7.2	227.	300.	300.	1
2	258.	6.5	262.5	6.7	219.	276.	284.	2
3	229.	5.8	243.7	6.2	212.	252.	259.	3
4	204.	5.2	225.3	5.7	207.	232.	238.	4
5	182.	4.6	207.0	5.3	204.	212.	220.	5
6	162.	4.1	192.0	4.9	201.	192.	203.	6
7	144.	3.7	177.0	4.5	199.	176.	180.	7
8	128.	3.3	162.0	4.1	197.	160.	165.	8
9	114.	2.91	148.3	3.77	194.	144.	148.	9
10	102.	2.59	135.0	3.43	191.	128.	134.	10
11	91.	2.30	120.5	3.06	188.	116.	120.	11
12	81.	2.05	105.5	2.68	185.	104.	109.	12
13	72.	1.83	91.5	2.32	182.	92.	95.	13
14	64.	1.63	80.0	2.03	180.	80.	83.	14
15	57.	1.45	72.0	1.83	178.	72.	72.	15
16	51.	1.29	62.5	1.59	175.	64.	65.	16
17	45.	1.15	54.0	1.37	172.	56.	58.	17
18	40.	1.02	47.5	1.21	168.	48.	49.	18
19	36.	0.91	41.0	1.04	164.	40.	42.	19
20	32.	.81	34.8	0.88	161.	36.	35.	20
21	28.5	.72	31.7	.81	157.	32.	32.	21
22	25.3	.62	28.6	.73	155.	28.	28.	22
23	22.6	.57	25.8	.66	153.	24.	25.	23
24	20.1	.51	23.0	.58	151.	22.	22.	24
25	17.9	.45	20.4	.52	148.	20.	20.	25
26	15.9	.40	18.1	.46	146.	18.	18.	26
27	14.2	.36	17.3	.439	143.	16.4	16.	27
28	12.6	.32	16.2	.411	139.	14.8	14.	28
29	11.3	.29	15.0	.381	134.	13.6	13.	29
30	10.0	.25	14.0	.356	127.	12.4	12.	30
31	8.9	.227	13.2	.335	120.	11.6	10.	31
32	8.0	.202	12.8	.325	115.	10.8	9.	32
33	7.1	.180	11.8	.300	112.	10.0	8.	33
34	6.3	.160	10.4	.264	110.	9.2	7.	34
35	5.6	.143	9.5	.241	108.	8.4	5.	35
36	5.0	.127	9.0	.229	106.	7.6	4.	36
37	4.5	.113	8.5	.216	103.	6.8		37
38	4.0	.101	8.0	.203	101.	6.0		38
39	3.5	.090	7.5	.191	99.	5.2		39
40	3.1	.080	7.0	.178	97.	4.8		40
41			6.6	.168	95.	4.4		41
42			6.2	.157	92.	4.0		42
43			6.0	.152	88.	3.6		43
44			5.8	.147	85.	3.2		44
45			5.5	.140	81.	2.8		45
46			5.2	.132	79.	2.4		46
47			5.0	.127	77.	2.0		47
48			4.8	.122	75.	1.6		48
49			4.6	.117	72.	1.2		49
50			4.4	.112	69.	1.0		50

* The Steel Wire Gage is the same gage which has been known by the various names: "Washburn and Moen," "Roebling," "American Steel and Wire Co.'s." Its abbreviation should be written "Stl. W. G.," to distinguish it from "S. W. G.," the usual abbreviation for the (British) Standard Wire Gage.

† The American Wire Gage sizes have been rounded off to the usual limits of commercial accuracy. They are given to four significant figures in Tables 499 to 502. They can be calculated with any desired accuracy, being based upon a simple mathematical law. The diameter of No. 0000 is defined as 0.4600 inch and of No. 36 as 0.0050 inch. The ratio of any diameter to the diameter of the next greater number $\sqrt[39]{\frac{.4600}{.0050}} = 1.1229322$.

Taken from Circular No. 31. Copper Wire Tables, U.S. Bureau of Standards which contains more complete tables.

Introduction to Wire Tables; Mass and Volume Resistivity of Copper and Aluminum

The following wire tables are abridged from those prepared by the Bureau of Standards at the request and with the coöperation of the Standards Committee of the American Institute of Electrical Engineers (Circular No. 31 of the Bureau of Standards). The standard of copper resistance used is "The International Annealed Copper Standard" as adopted Sept. 5, 1913, by the International Electrotechnical Commission and represents the average commercial high-conductivity copper for the purpose of electric conductors. This standard corresponds to a conductivity of 58×10^{-5} c.g.s. units, and a density of 8.89, at 20° C.

In the various units of mass resistivity and volume resistivity this may be stated as

0.15328 ohm (meter, gram) at 20° C.
875.20 ohms (mile, pound) at 20° C.
1.7241 microhm-cm at 20° C.
0.67879 microhm-inch at 20° C.
10.371 ohms (mil, foot) at 20° C.

The temperature coefficient for this particular resistivity is $\alpha_{20} = 0.00393$, or $\alpha_0 = 0.00427$. The temperature coefficient of copper is proportional to the conductivity, so that where the conductivity is known the temperature coefficient may be calculated, and vice-versa. Thus the next table shows the temperature coefficients of copper having various percentages of the standard conductivity. A consequence of this relation is that the change of *resistivity* per degree is constant, independent of the sample of copper and independent of the temperature of reference. This resistivity-temperature constant, for volume resistivity and Centigrade degrees, is 0.00681 microhm cm, and for mass resistivity is 0.000597 ohm (meter, gram).

The density of 8.89 grams per cubic centimeter at 20° C, is equivalent to 0.32117 pounds per cubic inch.

The values in the following tables are for annealed copper of standard resistivity. The user of the tables must apply the proper correction for copper of other resistivity. Hard-drawn copper may be taken as about 2.7 per cent higher resistivity than annealed copper.

The following is a fair average of the chemical content of commercial high conductivity copper:

Copper	99.91%	Sulphur	0.002%
Silver	.03	Iron	.002
Oxygen	.052	Nickel	Trace
Arsenic	.002	Lead	"
Antimony	.002	Zinc	"

The following values are consistent with the data above:

Conductivity at 0° C, in c.g.s. electromagnetic units	62.969×10^{-5}
Resistivity at 0° C, in microhm-cms	1.5881
Density at 0° C	8.90
Coefficient of linear expansion per degree C	0.000017
"Constant mass" temperature coefficient of resistance at 0° C.	0.00427

The aluminum tables are based on a figure for the conductivity published by the U. S. Bureau of Standards, which is the result of many thousands of determinations by the Aluminum Company of America. A volume resistivity of 2.828 microhm-cm and a density of 2.70 may be considered to be good average values for commercial hard-drawn aluminum. These values give:

Conductivity at 0° C in c.g.s. electromagnetic units	38.36×10^{-6}
Mass resistivity, in ohms (meter, gram) at 20° C	0.0764
" " " " (mile, pound) at 20° C	436.
Mass per cent conductivity relative to copper	200.7%
Volume resistivity, in microhm-cm at 20° C	2.828
" " in microhm-inch at 20° C	1.113
Volume per cent conductivity relative to copper	61.0%
Density, in grams per cubic centimeter	2.70
Density, in pounds per cubic inch	0.0975

The average chemical content of commercial aluminum wire is

Aluminum	99.57%
Silicon	0.29
Iron	0.14

COPPER WIRE

TABLE 497.—Temperature Coefficients of Copper for Different Initial Temperatures (Centigrade) and Different Conductivities

Ohms (meter, gram) at 20° C.	Per cent conductivity.	α_0	α_{15}	α_{20}	α_{25}	α_{30}	α_{50}
0.161 34	95%	0.004 03	0.003 80	0.003 73	0.003 67	0.003 60	0.003 36
.159 66	96%	.004 08	.003 85	.003 77	.003 70	.003 64	.003 39
.158 02	97%	.004 13	.003 89	.003 81	.003 74	.003 67	.003 42
.157 53	97.3%	.004 14	.003 90	.003 82	.003 75	.003 68	.003 43
.156 40	98%	.004 17	.003 93	.003 85	.003 78	.003 71	.003 45
.154 82	99%	.004 22	.003 97	.003 89	.003 82	.003 74	.003 48
.153 28	100%	.004 27	.004 01	**.003 93**	.003 85	.003 78	.003 52
.151 76	101%	.004 31	.004 05	.00 397	.003 89	.003 82	.003 55

NOTE. — The fundamental relation between resistance and temperature is the following:

$$R_t = R_{t_1}(1 + \alpha_{t_1}[t - t_1]),$$

where α_{t_1} is the "temperature coefficient," and t_1 is the "initial temperature" or "temperature of reference."

The values of α in the above table exhibit the fact that the temperature coefficient of copper is proportional to the conductivity. The table was calculated by means of the following formula, which holds for any per cent conductivity, n, within commercial ranges, and for centigrade temperatures. (n is considered to be expressed decimally: e.g., if per cent conductivity = 99 per cent, $n = 0.99$.)

$$\alpha_{t_1} = \frac{1}{\frac{1}{n(0.00393)} + (t_1 - 20)}.$$

TABLE 498.—Reduction of Observations to Standard Temperature (Copper)

Temperature C.	Corrections to reduce Resistivity to 20° C.				Factors to reduce Resistance to 20° C.			Temperature C.
	Ohm (meter, gram).	Microhm—cm.	Ohm (mile, pound).	Microhm—inch.	For 96 per cent conductivity.	For 98 per cent conductivity.	For 100 per cent conductivity.	
0	+0.011 94	+0.1361	+ 68.20	+0.053 58	1.0816	1.0834	1.0853	0
5	+ .008 96	+ .1021	+ 51.15	+ .040 18	1.0600	1.0613	1.0626	5
10	+ .005 97	+ .0681	+ 34.10	+ .026 79	1.0392	1.0401	1.0409	10
11	+ .005 37	+ .0612	+ 30.69	+ .024 11	1.0352	1.0359	1.0367	11
12	+ .004 78	+ .0544	+ 27.28	+ .021 43	1.0311	1.0318	1.0325	12
13	+ .004 18	+ .0476	+ 23.87	+ .018 75	1.0271	1.0277	1.0283	13
14	+ .003 58	+ .0408	+ 20.46	+ .016 07	1.0232	1.0237	1.0242	14
15	+ .002 99	+ .0340	+ 17.05	+ .013 40	1.0192	1.0196	1.0200	15
16	+ .002 39	+ .0272	+ 13.64	+ .010 72	1.0153	1.0156	1.0160	16
17	+ .001 79	+ .0204	+ 10.23	+ .008 04	1.0114	1.0117	1.0119	17
18	+ .001 19	+ .0136	+ 6.82	+ .005 36	1.0076	1.0078	1.0070	18
19	+ .000 60	+ .0068	+ 3.41	+ .002 68	1.0038	1.0039	1.0039	19
20	0	0	0	0	1.0000	1.0000	1.0000	20
21	− .000 60	− .0068	− 3.41	− .002 68	0.9962	0.9962	0.9961	21
22	− .001 19	− .0136	− 6.82	− .005 36	.9925	.9924	.9922	22
23	− .001 79	− .0204	− 10.23	− .008 04	.9888	.9886	.9883	23
24	− .002 39	− .0272	− 13.64	− .010 72	.9851	.9848	.9845	24
25	− .002 99	− .0340	− 17.05	− .013 40	.9815	.9811	.9807	25
26	− .003 58	− .0408	− 20.46	− .016 07	.9779	.9774	.9770	26
27	− .004 18	− .0476	− 23.87	− .018 75	.9743	.9737	.9732	27
28	− .004 78	− .0544	− 27.28	− .021 43	.9707	.9701	.9695	28
29	− .005 37	− .0612	− 30.69	− .024 11	.9672	.9665	.9658	29
30	− .005 97	− .0681	− 34.10	− .026 79	.9636	.9629	.9622	30
35	− .008 96	− .1021	− 51.15	− .040 18	.9464	.9454	.9443	35
40	− .011 94	− .1361	− 68.20	− .053 58	.9298	.9285	.9271	40
45	− .014 93	− .1701	− 85.25	− .066 98	.9138	.9122	.9105	45
50	− .017 92	− .2042	−102.30	− .080 37	.8983	.8964	.8945	50
55	− .020 90	− .2382	−119.35	− .093 76	.8833	.8812	.8791	55
60	− .023 89	− .2722	−136.40	− .107 16	.8689	.8665	.8642	60
65	− .026 87	− .3062	−153.45	− .120 56	.8549	.8523	.8407	65
70	− .029 86	− .3403	−170.50	− .133 95	.8413	.8385	.8358	70
75	− .032 85	− .3743	−187.55	− .147 34	.8281	.8252	.8223	75

WIRE TABLE, STANDARD ANNEALED COPPER

American Wire Gage (B. & S.). English Units

Gage No.	Diameter in Mils. at 20° C.	Cross-Section at 20° C. Circular Mils.	Cross-Section at 20° C. Square Inches.	Ohms per 1000 Feet.* 0° C (= 32° F.)	20° C (= 68° F.)	50° C (= 122° F.)	75° C (= 167° F.)
0000	460.0	211 600.	0.1662	0.045 16	0.049 01	0.054 79	0.059 61
000	409.6	167 800.	.1318	.056 95	.061 80	.069 09	.075 16
00	364.8	133 100.	.1045	.071 81	.077 93	.087 12	.094 78
0	324.9	105 500.	.082 89	.090 55	.098 27	.1099	.1195
1	289.3	83 690.	.065 73	.1142	.1239	.1385	.1507
2	257.6	66 370.	.052 13	.1440	.1563	.1747	.1900
3	229.4	52 640.	.041 34	.1816	.1970	.2203	.2396
4	204.3	41 740.	.032 78	.2289	.2485	.2778	.3022
5	181.9	33 100.	.026 00	.2887	.3133	.3502	.3810
6	162.0	26 250.	.020 62	.3640	.3951	.4416	.4805
7	144.3	20 820	.016 35	.4590	.4982	.5569	.6059
8	128.5	16 510.	.012 97	.5788	.6282	.7023	.7640
9	114.4	13 090.	.010 28	.7299	.7921	.8855	.9633
10	101.9	10 380.	.008 155	.9203	.9989	1.117	1.215
11	90.74	8234.	.006 467	1.161	1.260	1.408	1.532
12	80.81	6530.	.005 129	1.463	1.588	1.775	1.931
13	71.96	5178.	.004 067	1.845	2.003	2.239	2.436
14	64.08	4107.	.003 225	2.327	2.525	2.823	3.071
15	57.07	3257.	.002 558	2.934	3.184	3.560	3.873
16	50.82	2583.	.002 028	3.700	4.016	4.489	4.884
17	45.26	2048.	.001 609	4.666	5.064	5.660	6.158
18	40.30	1624.	.001 276	5.883	6.385	7.138	7.765
19	35.89	1288.	.001 012	7.418	8.051	9.001	9.792
20	31.96	1022.	.000 802 3	9.355	10.15	11.35	12.35
21	28.45	810.1	.000 636 3	11.80	12.80	14.31	15.57
22	25.35	642.4	.000 504 6	14.87	16.14	18.05	19.63
23	22.57	509.5	.000 400 2	18.76	20.36	22.76	24.76
24	20.10	404.0	.000 317 3	23.65	25.67	28.70	31.22
25	17.90	320.4	.000 251 7	29.82	32.37	36.18	39.36
26	15.94	254.1	.000 199 6	37.61	40.81	45.63	49.64
27	14.20	201.5	.000 158 3	47.42	51.47	57.53	62.59
28	12.64	159.8	.000 125 5	59.80	64.90	72.55	78.93
29	11.26	126.7	.000 099 53	75.40	81.83	91.48	99.52
30	10.03	100.5	.000 078 94	95.08	103.2	115.4	125.5
31	8.928	79.70	.000 062 60	119.9	130.1	145.5	158.2
32	7.950	63.21	.000 049 64	151.2	164.1	183.4	199.5
33	7.080	50.13	.000 039 37	190.6	206.9	231.3	251.6
34	6.305	39.75	.000 031 22	240.4	260.9	291.7	317.3
35	5.615	31.52	.000 024 76	303.1	329.0	367.8	400.1
36	5.000	25.00	.000 019 64	382.2	414.8	463.7	504.5
37	4.453	19.83	.000 015 57	482.0	523.1	584.8	636.2
38	3.965	15.72	.000 012 35	607.8	659.6	737.4	802.2
39	3.531	12.47	.000 009 793	766.4	831.8	929.8	1012.
40	3.145	9.888	.000 007 766	966.5	1049.	1173.	1276.

* Resistance at the stated temperatures of a wire whose length is 1000 feet at 20° C.

WIRE TABLE, STANDARD ANNEALED COPPER

American Wire Gage (B. & S.). English Units

Gage No.	Diameter in Mils. at 20° C.	Pounds per 1000 Feet.	Feet per Pound.	Feet per Ohm.* 0° C (=32° F.)	20° C (=68° F.)	50° C (=122° F.)	75° C (=167° F.)
0000	460.0	640.5	1.561	22 140.	20 400.	18 250.	16 780.
000	409.6	507.9	1.968	17 560.	16 180.	14 470.	13 300.
00	364.8	402.8	2.482	13 930.	12 830.	11 480.	10 550.
0	324.9	319.5	3.130	11 040.	10 180.	9103.	8367.
1	289.3	253.3	3.947	8758.	8070.	7219.	6636.
2	257.6	200.9	4.977	6946.	6400.	5725.	5262.
3	229.4	159.3	6.276	5508.	5075.	4540.	4173.
4	204.3	126.4	7.914	4368.	4025.	3600.	3309.
5	181.9	100.2	9.980	3464.	3192.	2855.	2625.
6	162.0	79.46	12.58	2747.	2531.	2264.	2081.
7	144.3	63.02	15.87	2179.	2007.	1796.	1651.
8	128.5	49.98	20.01	1728.	1592.	1424.	1309.
9	114.4	39.63	25.23	1370.	1262.	1129.	1038.
10	101.9	31.43	31.82	1087.	1001.	895.6	823.2
11	90.74	24.92	40.12	861.7	794.0	710.2	652.8
12	80.81	19.77	50.59	683.3	629.6	563.2	517.7
13	71.96	15.68	63.80	541.9	499.3	446.7	410.6
14	64.08	12.43	80.44	429.8	396.0	354.2	325.6
15	57.07	9.858	101.4	340.8	314.0	280.9	258.2
16	50.82	7.818	127.9	270.3	249.0	222.8	204.8
17	45.26	6.200	161.3	214.3	197.5	176.7	162.4
18	40.30	4.917	203.4	170.0	156.6	140.1	128.8
19	35.89	3.899	256.5	134.8	124.2	111.1	102.1
20	31.96	3.092	323.4	106.9	98.50	88.11	80.99
21	28.46	2.452	407.8	84.78	78.11	69.87	64.23
22	25.35	1.945	514.2	67.23	61.95	55.41	50.94
23	22.57	1.542	648.4	53.32	49.13	43.94	40.39
24	20.10	1.223	817.7	42.28	38.96	34.85	32.03
25	17.90	0.9699	1031.	33.53	30.90	27.64	25.40
26	15.94	.7692	1300.	26.59	24.50	21.92	20.15
27	14.20	.6100	1639.	21.09	19.43	17.38	15.98
28	12.64	.4837	2067.	16.72	15.41	13.78	12.67
29	11.26	.3836	2607.	13.26	12.22	10.93	10.05
30	10.03	.3042	3287.	10.52	9.691	8.669	7.968
31	8.928	.2413	4145.	8.341	7.685	6.875	6.319
32	7.950	.1913	5227.	6.614	6.095	5.452	5.011
33	7.080	.1517	6591.	5.245	4.833	4.323	3.974
34	6.305	.1203	8310.	4.160	3.833	3.429	3.152
35	5.615	.095 42	10 480.	3.299	3.040	2.719	2.499
36	5.000	.075 68	13 210.	2.616	2.411	2.156	1.982
37	4.453	.060 01	16 660.	2.075	1.912	1.710	1.572
38	3.965	.047 59	21 010.	1.645	1.516	1.356	1.247
39	3.531	.037 74	26 500.	1.305	1.202	1.075	0.9886
40	3.145	.029 93	33 410.	1.035	0.9534	0.8529	.7840

* Length at 20° C of a wire whose resistance is 1 ohm at the stated temperatures.

WIRE TABLE, STANDARD ANNEALED COPPER

American Wire Gage (B. & S.). English Units

Gage No.	Diameter in Mils. at 20° C.	Ohms per Pound.			Pounds per Ohm.
		0° C (=32° F.)	20° C (=68° F.)	50° C (=122° F.)	20° C (=68° F.)
0000	460.0	0.000 070 51	0.000 076 52	0.000 085 54	13 070.
000	409.6	.000 1121	.000 1217	.000 1360	8219.
00	364.8	.000 1783	.000 1935	.000 2163	5169.
0	324.9	.000 2835	.000 3076	.000 3439	3251.
1	289.3	.000 4507	.000 4891	.000 5468	2044.
2	257.6	.000 7166	.000 7778	.000 8695	1286.
3	229.4	.001 140	.001 237	.001 383	808.6
4	204.3	.001 812	.001 966	.002 198	508.5
5	181.9	.002 881	.003 127	.003 495	319.8
6	162.0	.004 581	.004 972	.005 558	201.1
7	144.3	.007 284	.007 905	.008 838	126.5
8	128.5	.011 58	.012 57	.014 05	79.55
9	114.4	.018 42	.019 99	.022 34	50.03
10	101.9	.029 28	.031 78	.035 53	31.47
11	90.74	.046 56	.050 53	.056 49	19.79
12	80.81	.074 04	.080 35	.089 83	12.45
13	71.96	.1177	.1278	.1428	7.827
14	64.08	.1872	.2032	.2271	4.922
15	57.07	.2976	.3230	.3611	3.096
16	50.82	.4733	.5136	.5742	1.947
17	45.26	.7525	.8167	.9130	1.224
18	40.30	1.197	1.299	1.452	0.7700
19	35.89	1.903	2.065	2.308	.4843
20	31.96	3.025	3.283	3.670	.3046
21	28.46	4.810	5.221	5.836	.1915
22	25.35	7.649	8.301	9.280	.1205
23	22.57	12.16	13.20	14.76	.075 76
24	20.10	19.34	20.99	23.46	.047 65
25	17.90	30.75	33.37	37.31	.029 97
26	15.94	48.89	53.06	59.32	.018 85
27	14.20	77.74	84.37	94.32	.011 85
28	12.64	123.6	134.2	150.0	.007 454
29	11.26	196.6	213.3	238.5	.004 688
30	10.03	312.5	339.2	379.2	.002 948
31	8.928	497.0	539.3	602.9	.001 854
32	7.950	790.2	857.6	958.7	.001 166
33	7.080	1256.	1364.	1524.	.000 7333
34	6.305	1998.	2168.	2424.	.000 4612
35	5.615	3177.	3448.	3854.	.000 2901
36	5.000	5051.	5482.	6128.	.000 1824
37	4.453	8032.	8717.	9744.	.000 1147
38	3.965	12 770.	13 860.	15 490.	.000 072 15
39	3.531	20 310.	22 040.	24 640.	.000 045 38
40	3.145	32 290.	35 040.	39 170.	.000 028 54

WIRE TABLE, STANDARD ANNEALED COPPER

American Wire Gage (B. & S.). Metric Units

Gage No.	Diameter in mm at 20° C.	Cross Section in mm² at 20° C.	Ohms per Kilometer.* 0° C.	20° C.	50° C.	75° C.
0000	11.68	107.2	0.1482	0.1608	0.1798	0.1956
000	10.40	85.03	.1868	.2028	.2267	.2466
00	9.266	67.43	.2356	.2557	.2858	.3110
0	8.252	53.48	.2971	.3224	.3604	.3921
1	7.348	42.41	.3746	.4066	.4545	.4944
2	6.544	33.63	.4724	.5127	.5731	.6235
3	5.827	26.67	.5956	.6465	.7227	.7862
4	5.189	21.15	.7511	.8152	.9113	.9914
5	4.621	16.77	.9471	1.028	1.149	1.250
6	4.115	13.30	1.194	1.296	1.449	1.576
7	3.665	10.55	1.506	1.634	1.827	1.988
8	3.264	8.366	1.899	2.061	2.304	2.506
9	2.906	6.634	2.395	2.599	2.905	3.161
10	2.588	5.261	3.020	3.277	3.663	3.985
11	2.305	4.172	3.807	4.132	4.619	5.025
12	2.053	3.309	4.801	5.211	5.825	6.337
13	1.828	2.624	6.054	6.571	7.345	7.991
14	1.628	2.081	7.634	8.285	9.262	10.08
15	1.450	1.650	9.627	10.45	11.68	12.71
16	1.291	1.309	12.14	13.17	14.73	16.02
17	1.150	1.038	15.31	16.61	18.57	20.20
18	1.024	0.8231	19.30	20.95	23.42	25.48
19	0.9116	.6527	24.34	26.42	29.53	32.12
20	.8118	.5176	30.69	33.31	37.24	40.51
21	.7230	.4105	38.70	42.00	46.95	51.08
22	.6438	.3255	48.80	52.96	59.21	64.41
23	.5733	.2582	61.54	66.79	74.66	81.22
24	.5106	.2047	77.60	84.21	94.14	102.4
25	.4547	.1624	97.85	106.2	118.7	129.1
26	.4049	.1288	123.4	133.9	149.7	162.9
27	.3606	.1021	155.6	168.9	188.8	205.4
28	.3211	.080 98	196.2	212.9	238.0	258.9
29	.2859	.064 22	247.4	268.5	300.1	326.5
30	.2546	.050 93	311.9	338.6	378.5	411.7
31	.2268	.040 39	393.4	426.9	477.2	519.2
32	.2019	.032 03	496.0	538.3	601.8	654.7
33	.1798	.025 40	625.5	678.8	758.8	825.5
34	.1601	.020 14	788.7	856.0	956.9	1041.
35	.1426	.015 97	994.5	1079.	1207.	1313.
36	.1270	.012 67	1254.	1361.	1522.	1655.
37	.1131	.010 05	1581.	1716.	1919.	2087.
38	.1007	.007 967	1994.	2164.	2419.	2632.
39	.089 69	.006 318	2514.	2729.	3051.	3319.
40	.079 87	.005 010	3171.	3441.	3847.	4185.

*Resistance at the stated temperatures of a wire whose length is 1 kilometer at 20° C.

WIRE TABLE, STANDARD ANNEALED COPPER

American Wire Gage (B. & S.). Metric Units

Gage No.	Diameter in mm at 20° C.	Kilograms per Kilometer.	Meters per Gram.	Meters per Ohm.* 0° C.	Meters per Ohm.* 20° C.	Meters per Ohm.* 50° C.	Meters per Ohm.* 75° C.
0000	11.68	953.2	0.001 049	6749.	6219.	5563.	5113.
000	10.40	755.9	.001 323	5352.	4932.	4412.	4055.
00	9.266	599.5	.001 668	4245.	3911.	3499.	3216.
0	8.252	475.4	.002 103	3366.	3102.	2774.	2550.
1	7.348	377.0	.002 652	2669.	2460.	2200.	2022.
2	6.544	299.0	.003 345	2117.	1951.	1745.	1604.
3	5.827	237.1	.004 217	1679.	1547.	1384.	1272.
4	5.189	188.0	.005 318	1331.	1227.	1097.	1009.
5	4.621	149.1	.006 706	1056.	972.9	870.2	799.9
6	4.115	118.2	.008 457	837.3	771.5	690.1	634.4
7	3.665	93.78	.010 66	664.0	611.8	547.3	503.1
8	3.264	74.37	.013 45	526.6	485.2	434.0	399.0
9	2.906	58.98	.016 96	417.6	384.8	344.2	316.4
10	2.588	46.77	.021 38	331.2	305.1	273.0	250.9
11	2.305	37.09	.026 96	262.6	242.0	216.5	199.0
12	2.053	29.42	.034 00	208.3	191.9	171.7	157.8
13	1.828	23.33	.042 87	165.2	152.2	136.1	125.1
14	1.628	18.50	.054 06	131.0	120.7	108.0	99.24
15	1.450	14.67	.068 16	103.9	95.71	85.62	78.70
16	1.291	11.63	.085 95	82.38	75.90	67.90	62.41
17	1.150	9.226	.1084	65.33	60.20	53.85	49.50
18	1.024	7.317	.1367	51.81	47.74	42.70	39.25
19	0.9116	5.803	.1723	41.09	37.86	33.86	31.13
20	.8118	4.602	.2173	32.58	30.02	26.86	24.69
21	.7230	3.649	.2740	25.84	23.81	21.30	19.58
22	.6438	2.894	.3455	20.49	18.88	16.89	15.53
23	.5733	2.295	.4357	16.25	14.97	13.39	12.31
24	.5106	1.820	.5494	12.89	11.87	10.62	9.764
25	.4547	1.443	.6928	10.22	9.417	8.424	7.743
26	.4049	1.145	.8736	8.105	7.468	6.680	6.141
27	.3606	0.9078	1.102	6.428	5.922	5.298	4.870
28	.3211	.7199	1.389	5.097	4.697	4.201	3.862
29	.2859	.5709	1.752	4.042	3.725	3.332	3.063
30	.2546	.4527	2.209	3.206	2.954	2.642	2.429
31	.2268	.3590	2.785	2.542	2.342	2.095	1.926
32	.2019	.2847	3.512	2.016	1.858	1.662	1.527
33	.1798	.2258	4.429	1.599	1.473	1.318	1.211
34	.1601	.1791	5.584	1.268	1.168	1.045	0.9606
35	.1426	.1420	7.042	1.006	0.9265	0.8288	.7618
36	.1270	.1126	8.879	0.7974	.7347	.6572	.6041
37	.1131	.089 31	11.20	.6324	.5827	.5212	.4791
38	.1007	.070 83	14.12	.5015	.4621	.4133	.3799
39	.089 69	.056 17	17.80	.3977	.3664	.3278	.3013
40	.079 87	.044 54	22.45	.3154	.2906	.2600	.2390

* Length at 20° C of a wire whose resistance is 1 ohm at the stated temperatures.

WIRE TABLE, STANDARD ANNEALED COPPER

American Wire Gage (B. & S.). Metric Units

Gage No.	Diameter in mm at 20° C.	Ohms per Kilogram.			Grams per Ohm.
		0° C.	20° C.	50° C.	20° C.
0000	11.68	0.000 155 4	0.000 168 7	0.000 188 6	5 928 000.
000	10.40	.000 247 2	.000 268 2	.000 299 9	3 728 000.
00	9.266	.000 393 0	.000 426 5	.000 476 8	2 344 000.
0	8.252	.000 624 9	.000 678 2	.000 758 2	1 474 000.
1	7.348	.000 993 6	.001 078	.001 206	927 300.
2	6.544	.001 580	.001 715	.001 917	583 200.
3	5.827	.002 512	.002 726	.003 048	366 800.
4	5.189	.003 995	.004 335	.004 846	230 700.
5	4.621	.006 352	.006 893	.007 706	145 100.
6	4.115	.010 10	.010 96	.012 25	91 230.
7	3.665	.016 06	.017 43	.019 48	57 380.
8	3.264	.025 53	.027 71	.030 98	36 080.
9	2.906	.040 60	.044 06	.049 26	22 690.
10	2.588	.064 56	.070 07	.078 33	14 270.
11	2.305	.1026	.1114	.1245	8976.
12	2.053	.1632	.1771	.1980	56.45
13	1.828	.2595	.2817	.3149	3550.
14	1.628	.4127	.4479	.5007	2233.
15	1.450	.6562	.7122	.7961	1404.
16	1.291	1.043	1.132	1.266	883.1
17	1.150	1.659	1.801	2.013	555.4
18	1.024	2.638	2.863	3.201	349.3
19	0.9116	4.194	4.552	5.089	219.7
20	.8118	6.670	7.238	8.092	138.2
21	.7230	10.60	11.51	12.87	86.88
22	.6438	16.86	18.30	20.46	54.64
23	.5733	26.81	29.10	32.53	34.36
24	.5106	42.63	46.27	51.73	21.61
25	.4547	67.79	73.57	82.25	13.59
26	.4049	107.8	117.0	130.8	8.548
27	.3606	171.4	186.0	207.9	5.376
28	.3211	272.5	295.8	330.6	3.381
29	.2859	433.3	470.3	525.7	2.126
30	.2546	689.0	747.8	836.0	1.337
31	.2268	1096.	1189.	1329.	0.8410
32	.2019	1742.	1891.	2114.	.5289
33	.1798	2770.	3006.	3361.	.3326
34	.1601	4404.	4780.	5344.	.2092
35	.1426	7003.	7601.	8497.	.1316
36	.1270	11140.	12090.	13510.	.082 74
37	.1131	17710.	19220.	21480.	.052 04
38	.1007	28150.	30560.	34160.	.032 73
39	.089 69	44770.	48590.	54310.	.020 58
40	.079 87	71180.	77260.	86360.	.012 94

WIRE TABLE, ALUMINUM

Hard-Drawn Aluminum Wire at 20° C (68° F.)

American Wire Gage (B. & S.). English Units

Gage No.	Diameter in Mils.	Cross Section. Circular Mils.	Cross Section. Square Inches.	Ohms per 1000 Feet.	Pounds per 1000 Feet.	Pounds per Ohm.	Feet per Ohm.
0000	460.	212 000.	0.166	0.0804	195.	2420.	12 400.
000	410.	168 000.	.132	.101	154.	1520.	9860.
00	365.	133 000.	.105	.128	122.	957.	7820.
0	325.	106 000.	.0829	.161	97.0	602.	6200.
1	289.	83 700.	.0657	.203	76.9	379.	4920.
2	258.	66 400.	.0521	.256	61.0	238.	3900.
3	229.	52 600.	.0413	.323	48.4	150.	3090.
4	204.	41 700.	.0328	.408	38.4	94.2	2450.
5	182.	33 100.	.0260	.514	30.4	59.2	1950.
6	162.	26 300.	.0206	.648	24.1	37.2	1540.
7	144.	20 800.	.0164	.817	19.1	23.4	1220.
8	128.	16 500.	.0130	1.03	15.2	14.7	970.
9	114.	13 100	.0103	1.30	12.0	9.26	770.
10	102.	10 400.	.008 15	1.64	9.55	5.83	610.
11	91.	8230.	.006 47	2.07	7.57	3.66	484.
12	81.	6530.	.005 13	2.61	6.00	2.30	384.
13	72.	5180.	.004 07	3.29	4.76	1.45	304.
14	64.	4110.	.003 23	4.14	3.78	0.911	241.
15	57.	3260.	.002 56	5.22	2.99	.573	191.
16	51.	2580.	.002 03	6.59	2.37	.360	152.
17	45.	2050.	.001 61	8.31	1.88	.227	120.
18	40.	1620.	.001 28	10.5	1.49	.143	95.5
19	36.	1290.	.001 01	13.2	1.18	.0897	75.7
20	32.	1020.	.000 802	16.7	0.939	.0564	60.0
21	28.5	810.	.000 636	21.0	.745	.0355	47.6
22	25.3	642.	.000 505	26.5	.591	.0223	37.8
23	22.6	509.	.000 400	33.4	.468	.0140	29.9
24	20.1	404.	.000 317	42.1	.371	.008 82	23.7
25	17.9	320.	.000 252	53.1	.295	.005 55	18.8
26	15.9	254	.000 200	67.0	.234	.003 49	14.9
27	14.2	202.	.000 158	84.4	.185	.002 19	11.8
28	12.6	160.	.000 126	106.	.147	.001 38	9.39
29	11.3	127.	.000 099 5	134.	.117	.000 868	7.45
30	10.0	101.	.000 078 9	169.	.0924	.000 546	5.91
31	8.9	79.7	.000 062 6	213.	.0733	.000 343	4.68
32	8.0	63.2	.000 049 6	269.	.0581	.000 216	3.72
33	7.1	50.1	.000 039 4	339.	.0461	.000 136	2.95
34	6.3	39.8	.000 031 2	428.	.0365	.000 085 4	2.34
35	5.6	31.5	.000 024 8	540.	.0290	.000 053 7	1.85
36	5.0	25.0	.000 019 6	681.	.0230	.000 033 8	1.47
37	4.5	19.8	.000 015 6	858.	.0182	.000 021 2	1.17
38	4.0	15.7	.000 012 3	1080.	.0145	.000 013 4	0.924
39	3.5	12.5	.000 009 79	1360.	.0115	.000 008 40	.733
40	3.1	9.9	.000 007 77	1720.	.0091	.000 005 28	.581

WIRE TABLE, ALUMINUM

Hard-Drawn Aluminum Wire at 20° C (68° F.)

American Wire Gage (B. & S.). Metric Units

Gage No.	Diameter in mm.	Cross Section in mm.²	Ohms per Kilometer.	Kilograms per Kilometer.	Grams per Ohm.	Meters per Ohm.
0000	11.7	107.	0.264	289.	1 100 000.	3790.
000	10.4	85.0	.333	230.	690 000.	3010.
00	9.3	67.4	.419	182.	434 000.	2380.
0	8.3	53.5	.529	144.	273 000.	1890.
1	7.3	42.4	.667	114.	172 000.	1500.
2	6.5	33.6	.841	90.8	108 000.	1190.
3	5.8	26.7	1.06	72.0	67 900.	943.
4	5.2	21.2	1.34	57.1	42 700.	748.
5	4.6	16.8	1.69	45.3	26 900.	593.
6	4.1	13.3	2.13	35.9	16 900.	470.
7	3.7	10.5	2.68	28.5	10 600.	373.
8	3.3	8.37	3.38	22.6	6680.	296.
9	2.91	6.63	4.26	17.9	4200.	235.
10	2.59	5.26	5.38	14.2	2640.	186.
11	2.30	4.17	6.78	11.3	1660.	148.
12	2.05	3.31	8.55	8.93	1050.	117.
13	1.83	2.62	10.8	7.08	657.	92.8
14	1.63	2.08	13.6	5.62	413.	73.6
15	1.45	1.65	17.1	4.46	260.	58.4
16	1.29	1.31	21.6	3.53	164.	46.3
17	1.15	1.04	27.3	2.80	103.	36.7
18	1.02	0.823	34.4	2.22	64.7	29.1
19	0.91	.653	43.3	1.76	40.7	23.1
20	.81	.518	54.6	1.40	25.6	18.3
21	.72	.411	68.9	1.11	16.1	14.5
22	.64	.326	86.9	0.879	10.1	11.5
23	.57	.258	110.	.697	6.36	9.13
24	.51	.205	138.	.553	4.00	7.24
25	.45	.162	174.	.438	2.52	5.74
26	.40	.129	220.	.348	1.58	4.55
27	.36	.102	277.	.276	0.995	3.61
28	.32	.0810	349.	.219	.626	2.86
29	.29	.0642	440.	.173	.394	2.27
30	.25	.0509	555.	.138	.248	1.80
31	.227	.0404	700.	.109	.156	1.43
32	.202	.0320	883.	.0865	.0979	1.13
33	.180	.0254	1110.	.0686	.0616	0.899
34	.160	.0201	1400.	.0544	.0387	.712
35	.143	.0160	1770.	.0431	.0244	.565
36	.127	.0127	2230.	.0342	.0153	.448
37	.113	.0100	2820.	.0271	.00963	.355
38	.101	.0080	3550.	.0215	.00606	.282
39	.090	.0063	4480.	.0171	.00381	.223
40	.080	.0050	5640.	.0135	.00240	.177

ELECTROCHEMICAL EQUIVALENTS

Every gram-ion involved in an electrolytic change requires the same number of coulombs or ampere-hours of electricity per unit change of valency. This constant is 96.494 coulombs or 26.804 ampere-hours per gram-hour (a faraday) corresponding to an electrochemical equivalent for silver of 0.00111803 gram sec.$^{-1}$ amp.$^{-1}$. It is to be noted that the *change of valence* of the element from its state before to that after the electrolytic action should be considered. The valence of a free, uncombined element is to be considered as 0. The same current will electrolyze "chemically equivalent" quantities per unit time. The valence is then included in the "chemically equivalent" quantity.

Element	Change of valency	Mg per coulomb	Coulombs per mg	Grams per amp. hour	Element	Change of valency	Mg per coulomb	Coulombs per mg	Grams per amp. hour
Al	3	0.09317	10.731	0.3354	Ni	1	0.6082	1.6442	2.1895
Cl	1	.36746	2.7213	1.3229	"	2	.3041	3.2884	1.0948
"	3	.12249	8.1649	.4410	"	3	.20273	4.9326	.7298
"	5	.07349	13.606	.2646	O	2	.082909	12.0611	.298500
"	7	.05249	19.049	.18891	"	4	.041454	24.1222	.149250
Cu	1	.6588	1.5179	2.3717	Pt	2	1.01165	.98848	3.6419
"	2	.3294	3.0358	1.1858	"	4	.50582	1.97696	1.8210
Au	1	2.044	.4893	7.357	"	6	.33722	2.9654	1.2140
"	3	.6813	1.468	2.452	K	1	.4052	2.467	1.4587
H	1	.0104442	95.747	.0375991	Ag	1	1.11803	.894430	4.02491
Pb	1	2.1475	.46565	7.7310	Na	1	.23833	4.1958	.85799
"	2	1.07375	.93130	3.8655	Sn	2	.61505	1.6259	2.2142
"	4	.53688	1.8626	1.9328	"	4	.30752	3.2518	1.1071
Hg	1	2.0790	.48100	7.4844	Zn	2	.33875	2.9520	1.21950
"	2	1.0395	.96200	3.7422					

The electrochemical equivalent for silver is 0.00111803 g sec.$^{-1}$ amp.$^{-1}$.
For other elements the electrochemical equivalent = (atomic weight divided by change of valency) times 1/96494 g/sec./amp. or g/coulomb.

NOTE.—The change of valency for O_2 is usually 2, etc.

TABLE 504.—Conductivity of Electrolytic Solutions

This subject has occupied the attention of a considerable number of eminent workers in molecular physics, and a few results are here tabulated. It has seemed better to confine the examples to the work of one experimenter, and the tables are quoted from a paper by F. Kohlrausch,* who has been one of the most reliable and successful workers in this field.

The study of electrolytic conductivity, especially in the case of very dilute solutions, has furnished material for generalizations, which may to some extent help in the formation of a sound theory of the mechanism of such conduction. If the solutions are made such that per unit volume of the solvent medium there are contained amounts of the salt proportional to its electrochemical equivalent, some simple relations become apparent. The solutions used by Kohlrausch were therefore made by taking numbers of grams of the pure salts proportional to their electrochemical equivalent, and using a liter of water as the standard of quantity of the solvent. Taking the electrochemical equivalent number as the chemical equivalent or atomic weight divided by the valence, and using this number of grams to the liter of water, we get what is called the normal or gram molecule per liter solution. In the table, m is used to represent the number of gram molecules to the liter of water in the solution for which the conductivities are tabulated. The conductivities were obtained by measuring the resistance of a cell filled with the solution by means of a Wheatstone bridge alternating current and telephone arrangement. The results are for 18° C, and relative to mercury at 0° C, the cell having been standardized by filling with mercury and measuring the resistance. They are supposed to be accurate to within one per cent of the true value.

The tabular numbers were obtained from the measurements in the following manner: —

Let K_{18} = conductivity of the solution at 18° C relative to mercury at 0° C.

K^{w}_{18} = conductivity of the solvent water at 18° C relative to mercury at 0° C.

Then $K_{18} - K^{w}_{18} = k_{18}$ = conductivity of the electrolyte in the solution measured.

$\frac{k_{18}}{m} = \mu$ = conductivity of the electrolyte in the solution per molecule, or the "specific molecular conductivity."

Value of k_{18} for a few Electrolytes

This short table illustrates the apparent law that the conductivity in very dilute solutions is proportional to the amount of salt dissolved.

m	KCl	NaCl	$AgNO_3$	$KC_2H_3O_2$	K_2SO_4	$MgSO_4$
0.00001	1.216	1.024	1.080	0.939	1.275	1.056
0.00002	2.434	2.056	2.146	1.886	2.532	2.104
0.00006	7.272	6.162	6.462	5.610	7.524	6.216
0.0001	12.09	10.29	10.78	9.34	12.49	10.34

TABLE 505.—Electro-Chemical Equivalents and Normal Solutions

The following table of the electro-chemical equivalent numbers and the densities of approximately normal solutions of the salts quoted in Table 506 may be convenient. They represent grams per cubic centimeter of the solution at the temperature given.

Salt dissolved.	Grams per liter.	m	Temp. C.	Density.	Salt dissolved.	Grams per liter.	m	Temp. C.	Density.
KCl	74.59	1.0	15.2	1.0457	$\frac{1}{2}K_2SO_4$	87.16	1.0	18.9	1.0658
NH_4Cl	53.55	1.0009	18.6	1.0152	$\frac{1}{2}Na_2SO_4$	71.09	1.0003	18.6	1.0602
NaCl	58.50	1.0	18.4	1.0391	$\frac{1}{2}Li_2SO_4$	55.09	1.0007	18.6	1.0445
LiCl	42.48	1.0	18.4	1.0227	$\frac{1}{2}MgSO_4$	60.17	1.0023	18.6	1.0573
$\frac{1}{2}BaCl_2$	104.0	1.0	18.6	1.0888	$\frac{1}{2}ZnSO_4$	80.58	1.0	5.3	1.0794
$\frac{1}{2}ZnCl_2$	68.0	1.012	15.0	1.0592	$\frac{1}{2}CuSO_4$	79.9	1.001	18.2	1.0776
KI	165.9	1.0	18.6	1.1183	$\frac{1}{2}K_2CO_3$	69.17	1.0006	18.3	1.0576
KNO_3	101.17	1.0	18.6	1.0601	$\frac{1}{2}Na_2CO_3$	53.04	1.0	17.9	1.0517
$NaNO_3$	85.08	1.0	18.7	1.0542	KOH	56.27	1.0025	18.8	1.0477
$AgNO_3$	169.9	1.0	–	–	HCl	36.51	1.0041	18.6	1.0161
$\frac{1}{2}Ba(NO_3)_2$	65.28	0.5	–	–	HNO_3	63.13	1.0014	18.6	1.0318
$KClO_3$	61.29	0.5	18.3	1.0367	$\frac{1}{2}H_2SO_4$	49.06	1.0006	18.9	1.0300
$KC_2H_3O_2$	98.18	1.0005	18.6	1.0467					

* "Wied. Ann." vol. 26, pp. 161–226, 1885.

TABLE 506

SPECIFIC MOLECULAR CONDUCTIVITY OF SOLUTIONS
MERCURY = 10^8

Salt dissolved.	$m = 10$	5	3	1	0.5	0.1	.05	.03	.01
$\frac{1}{2}K_2SO_4$	–	–	–	–	672	736	897	959	1098
KCl	–	–	827	919	958	1047	1083	1107	1147
KI	–	770	900	968	997	1069	1102	1123	1161
NH_4Cl	–	752	825	907	948	1035	1078	1101	1142
KNO_3	–	–	572	752	839	983	1037	1067	1122
$\frac{1}{2}BaCl_2$	–	–	487	658	725	861	904	939	1006
$KClO_3$	–	–	–	–	799	927	(976)	1006	1053
$\frac{1}{2}BaN_2O_6$	–	–	–	–	531	755	828	(870)	951
$\frac{1}{2}CuSO_4$	–	–	150	241	288	424	479	537	675
$AgNO_3$	–	351	448	635	728	886	936	(966)	1017
$\frac{1}{2}ZnSO_4$	–	82	146	249	302	431	500	556	685
$\frac{1}{2}MgSO_4$	–	82	151	270	330	474	532	587	715
$\frac{1}{2}Na_2SO_4$	–	–	–	475	559	734	784	828	906
$\frac{1}{2}ZnCl_2$	60	180	280	514	601	768	817	851	915
$NaCl$	–	398	528	695	757	865	897	(920)	962
$NaNO_3$	–	–	430	617	694	817	855	877	907
$KC_2H_3O_2$	30	240	381	594	671	784	820	841	879
$\frac{1}{2}Na_2CO_3$	–	–	254	427	510	682	751	799	899
$\frac{1}{2}H_2SO_4$	660	1270	1560	1820	1899	2084	2343	2515	2855
C_2H_4O	0.5	2.6	5.2	12	19	43	62	79	132
HCl	600	1420	2010	2780	3017	3244	3330	3369	3416
HNO_3	610	1470	2070	2770	2991	3225	3289	3328	3395
$\frac{1}{3}H_3PO_4$	148	160	170	200	250	430	540	620	790
KOH	423	990	1314	1718	1841	1986	2045	2078	2124
NH_3	0.5	2.4	3.3	8.4	12	31	43	50	92

Salt dissolved.	.006	.002	.001	.0006	.0002	.0001	.00006	.00002	.00001
$\frac{1}{2}K_2SO_4$	1130	1181	1207	1220	1241	1249	1254	1266	1275
KCl	1162	1185	1193	1199	1209	1209	1212	1217	1216
KI	1176	1197	1203	1209	1214	1216	1216	1216	1207
NH_4Cl	1157	1180	1190	1197	1204	1209	1215	1209	1205
KNO_3	1140	1173	1180	1190	1199	1207	1220	1198	1215
$\frac{1}{2}BaCl_2$	1031	1074	1092	1102	1118	1126	1133	1144	1142
$KClO_3$	1068	1091	1101	1109	1119	1122	1126	1135	1141
$\frac{1}{2}BaN_2O_6$	982	1033	1054	1066	1084	1096	1100	1114	1114
$\frac{1}{2}CuSO_4$	740	873	950	987	1039	1062	1074	1084	1086
$AgNO_3$	1033	1057	1068	1069	1077	1078	1077	1073	1080
$\frac{1}{2}ZnSO_4$	744	861	919	953	1001	1023	1032	1047	1060
$\frac{1}{2}MgSO_4$	773	881	935	967	1015	1034	1036	1052	1056
$\frac{1}{2}Na_2SO_4$	933	980	998	1009	1026	1034	1038	1056	1054
$\frac{1}{2}ZnCl_2$	939	979	994	1004	1020	1029	1031	1035	1036
$NaCl$	976	998	1008	1014	1018	1029	1027	1028	1024
$NaNO_3$	921	942	952	956	966	975	970	972	975
$KC_2H_3O_2$	891	913	919	923	933	934	935	943	939
$\frac{1}{2}Na_2CO_3$	956	1010	1037	1046	988	874	790	715	697*
$\frac{1}{2}H_2SO_4$	3001	3240	3316	3342	3280	3118	2927	2077	1413*
C_2H_4O	170	283	380	470	796	995	1133	1328	1304*
HCl	3438	3455	3455	3440	3340	3170	2968	2057	1254*
HNO_3	3421	3448	3427	3408	3285	3088	2863	1904	1144*
$\frac{1}{3}H_3PO_4$	858	945	968	977	920	837	746	497	402*
KOH	2141	2140	2110	2074	1892	1689	1474	845	747*
NH_3	116	190	260	330	500	610	690	700	560*

* Acids and alkaline salts show peculiar irregularities.

SPECIFIC MOLECULAR CONDUCTIVITY OF SOLUTIONS

TABLE 507.—Limiting Values of μ

This table shows limiting values of $\mu = \frac{k}{m} . 10^8$ for infinite dilution for neutral salts, calculated from Table 305.

Salt.	μ	Salt.	μ	Salt.	μ	Salt.	μ
$\frac{1}{2}K_2SO_4$.	1280	$\frac{1}{2}BaCl_2$.	1150	$\frac{1}{2}MgSO_4$.	1080	$\frac{1}{2}H_2SO_4$.	3700
KCl . . .	1220	$\frac{1}{2}KClO_3$.	1150	$\frac{1}{2}Na_2SO_4$.	1060	HCl . .	3500
KI . . .	1220	$\frac{1}{2}BaN_2O_6$.	1120	$\frac{1}{2}ZnCl_2$ . .	1040	HNO_3 . .	3500
NH_4Cl . .	1210	$\frac{1}{2}CuSO_4$.	1100	NaCl . .	1030	$\frac{1}{3}H_3PO_4$.	1100
KNO_3 . .	1210	$AgNO_3$.	1090	$NaNO_3$.	980	KOH . .	2200
–	–	$\frac{1}{2}ZnSO_4$.	1080	$K_2C_2H_3O_2$	940	$\frac{1}{2}Na_2CO_3$.	1400

If the quantities in Table 507 be represented by curves, it appears that the values of the specific molecular conductivities tend toward a limiting value as the solution is made more and more dilute. Although these values are of the same order of magnitude, they are not equal, but depend on the nature of both the ions forming the electrolyte.

When the numbers in Table 508 are multiplied by Hittorf's constant, or 0.00011, quantities ranging between 0.14 and 0.10 are obtained which represent the velocities in millimetres per second of the ions when the electromotive force gradient is one volt per millimetre.

Specific molecular conductivities in general become less as the concentration is increased, which may be due to mutual interference. The decrease is not the same for different salts, but becomes much more rapid in salts of high valence.

Salts having acid or alkaline reactions show marked differences. They have small specific molecular conductivity in very dilute solutions, but as the concentration is increased the conductivity rises, reaches a maximum and again falls off. Kohlrausch does not believe that this can be explained by impurities. H_3PO_4 in dilute solution seems to approach a monobasic acid, while H_2SO_4 shows two maxima, and like H_3PO_4 approaches in very weak solution to a monobasic acid.

Kohlrausch concludes that the law of independent migration of the ions in media like water is sustained.

TABLE 508.—Temperature Coefficients

The temperature coefficient in general diminishes with dilution, and for very dilute solutions appears to approach a common value. The following table gives the temperature coefficient for solutions containing 0.01 gram molecule of the salt.

Salt.	Temp. Coeff	Salt.	Temp. Coeff.	Salt.	Temp. Coeff.	Salt.	Temp. Coeff.
KCl . . .	0.0221	KI . . .	0.0219	$\frac{1}{2}K_2SO_4$.	0.0223	$\frac{1}{2}K_2CO_3$ . .	0.0249
NH_4Cl . .	0.0226	KNO_3 . .	0.0216	$\frac{1}{2}Na_2SO_4$.	0.0240	$\frac{1}{2}Na_2CO_3$ . .	0.0265
NaCl . .	0.0238	$NaNO_3$ . .	0.0226	$\frac{1}{2}Li_2SO_4$.	0.0242	KOH . . .	0.0194
LiCl . . .	0.0232	$AgNO_3$ . .	0.0221	$\frac{1}{2}MgSO_4$.	0.0236	HCl . . .	0.0159
						HNO_3 . . .	0.0162
$\frac{1}{2}BaCl_2$ . .	0.0234	$\frac{1}{2}Ba(NO_3)_2$	0.0224	$\frac{1}{2}ZnSO_4$.	0.0234	$\frac{1}{2}H_2SO_4$ . .	0.0125
$\frac{1}{2}ZnCl_2$ . .	0.0239	$KClO_3$ . .	0.0219	$\frac{1}{2}CuSO_4$.	0.0229		
$\frac{1}{2}MgCl_2$.	0.0241	$KC_2H_3O_2$.	0.0229	–	–	$\frac{1}{2}H_2SO_4$ for $m = .001$	0.0159

THE EQUIVALENT CONDUCTIVITY OF SALTS, ACIDS AND BASES IN AQUEOUS SOLUTIONS

In the following table the equivalent conductance is expressed in reciprocal ohms. The concentration is expressed in milli-equivalents of solute per liter of solution at the temperature to which the conductance refers. (In the cases of potassium hydrogen sulphate and phosphoric acid the concentration is expressed in milli-formula-weights of solute, $KHSO_4$ or H_3PO_4, per liter of solution, and the values are correspondingly the modal, or "formal," conductances.) Except in the cases of the strong acids the conductance of the water was subtracted, and for sodium acetate, ammonium acetate and ammonium chloride the values have been corrected for the hydrolysis of the salts. The atomic weights used were those of the International Commission for 1905, referred to oxygen as 16.00. Temperatures are on the hydrogen gas scale.

$$\text{Concentration in } \frac{\text{gram equivalents}}{1000 \text{ liter}}.$$

$$\text{Equivalent conductance in } \frac{\text{reciprocal ohms per centimeter cube}}{\text{gram equivalents per cubic centimeter}}.$$

Substance.	Concentration.	Equivalent conductance at the following °C temperatures.									
		18°	25°	50°	75°	100°	128°	156°	218°	281°	306°
Potassium chloride	0	130.1	(152.1)	(232.5)	(321.5)	414	(519)	625	825	1005	1120
" "	2	126.3	146.4	–	–	393	–	588	779	930	1008
" "	10	122.4	141.5	215.2	295.2	377	470	560	741	874	910
" "	80	113.5	–	–	–	342	–	498	638	723	720
" "	100	112.0	129.0	194.5	264.6	336	415	490			
Sodium chloride	0	109.0	–	–	–	362	–	555	760	970	1080
" "	2	105.6	–	–	–	349	–	534	722	895	955
" "	10	102.0	–	–	–	336	–	511	685	820	860
" "	80	93.5	–	–	–	301	–	450	500	674	680
" "	100	92.0	–	–	–	296	–	442			
Silver nitrate	0	115.8	–	–	–	367	–	570	780	965	1065
" "	2	112.2	–	–	–	353	–	539	727	877	935
" "	10	108.0	–	–	–	337	–	507	673	790	818
" "	20	105.1	–	–	–	326	–	488	639		
" "	40	101.3	–	–	–	312	–	462	599	680	680
" "	80	96.5	–	–	–	294	–	432	552	614	604
" "	100	94.6	–	–	–	289					
Sodium acetate	0	78.1	–	–	–	285	–	450	660	–	924
" "	2	74.5	–	–	–	268	–	421	578	–	801
" "	10	71.2	–	–	–	253	–	396	542	–	702
" "	80	63.4	–	–	–	221	–	340	452		
Magnesium sulphate	0	114.1	–	–	–	426	–	690	1080		
" "	2	94.3	–	–	–	302	–	377	260		
" "	10	76.1	–	–	–	234	–	241	143		
" "	20	67.5	–	–	–	190	–	195	110		
" "	40	59.3	–	–	–	160	–	158	88		
" "	80	52.0	–	–	–	136	–	133	75		
" "	100	49.8	–	–	–	130	–	126			
" "	200	43.1	–	–	–	110	–	109			
Ammonium chloride	0	131.1	152.0	–	–	(415)	–	(628)	(841)	–	(1176)
" "	2	126.5	146.5	–	–	399	–	601	801	–	1031
" "	10	122.5	141.7	–	–	382	–	573	758	–	925
" "	30	118.1	–	–	–	–	–	–	–	–	828
Ammonium acetate	0	(99.8)	–	–	–	(338)	–	(523)			
" "	10	91.7	–	–	–	300	–	456			
" "	25	88.2	–	–	–	286	–	426			

From the investigations of Noyes, Melcher, Cooper, Eastman and Kato; Journal of the American Chemical Society, 30, p. 335, 1908.

TABLE 509 (*continued*)

THE EQUIVALENT CONDUCTIVITY OF SALTS, ACIDS AND BASES IN AQUEOUS SOLUTIONS

Substance.	Concentration.	Equivalent conductance at the following °C temperatures.									
		18°	25°	50°	75°	100°	128°	156°	218°	281°	306°
Barium nitrate	0	116.9	–	–	–	385	–	600	840	1120	1300
" "	2	109.7	–	–	–	352	–	536	715	828	824
" "	10	101.0	–	–	–	322	–	481	618	658	615
" "	40	88.7	–	–	–	280	–	412	507	503	448
" "	80	81.6	–	–	–	258	–	372	449	430	
" "	100	79.1	–	–	–	249					
Potassium sulphate	0	132.8	–	–	–	455	–	715	1065	1460	1725
" "	2	124.8	–	–	–	402	–	605	806	893	867
" "	10	115.7	–	–	–	365	–	537	672	687	637
" "	40	104.2	–	–	–	320	–	455	545	519	466
" "	80	97.2	–	–	–	294	–	415	482	448	396
" "	100	95.0	–	–	–	286					
Hydrochloric acid	0	379.0	–	–	–	850	–	1085	1265	1380	1424
" "	2	373.6	–	–	–	826	–	1048	1217	1332	1337
" "	10	368.1	–	–	–	807	–	1016	1168	1226	1162
" "	80	353.0	–	–	–	762	–	946	1044	1046	862
" "	100	350.6	–	–	–	754	–	929	1006		
Nitric acid	0	377.0	421.0	570	706	826	945	1047	(1230)	–	(1380)
" "	2	371.2	413.7	559	690	806	919	1012	1166	–	1156
" "	10	365.0	406.0	548	676	786	893	978			
" "	50	353.7	393.3	528	649	750	845	917			
" "	100	346.4	385.0	516	632	728	817	880	–	–	454*
Sulphuric acid	0	383.0	(429)	(591)	(746)	891	(1041)	1176	1505	–	(2030)
" "	2	353.9	390.8	501	561	571	551	536	563	–	637
" "	10	309.0	337.0	406	435	446	460	481	533		
" "	50	253.5	273.0	323	356	384	417	448	502		
" "	100	233.3	251.2	300	336	369	404	435	483	–	474*
Potassium hydrogen sulphate	2	455.3	506.0	661.0	754	784	773	754			
	50	295.5	318.3	374.4	403	422	446	477			
	100	263.7	283.1	329.1	354	375	402	435			
Phosphoric acid	0	338.3	376	510	631	730	839	930			
" "	2	283.1	311.9	401	464	498	508	489			
" "	10	203.0	222.0	273	300	308	298	274			
" "	50	122.7	132.6	157.8	168.6	168	158	142			
" "	100	96.5	104.0	122.7	129.9	128	120	108			
Acetic acid	0	(347.0)	–	–	–	(773)	–	(980)	(1165)	–	(1268)
" "	10	14.50	–	–	–	25.1	–	22.2	14.7		
" "	30	8.50	–	–	–	14.7	–	13.0	8.65		
" "	80	5.22	–	–	–	9.05	–	8.00	5.34		
" "	100	4.67	–	–	–	8.10	–	–	4.82	–	1.57
Sodium hydroxide	0	216.5	–	–	–	594	–	835	1060		
" "	2	212.1	–	–	–	582	–	814			
" "	20	205.8	–	–	–	559	–	771	930		
" "	50	200.6	–	–	–	540	–	738	873		
Barium hydroxide	0	222	256	389	(520)	645	(760)	847			
" "	2	215	–	359	4	591					
" "	10	207	235	342	449	548	664	722			
" "	50	191.1	215.1	308	399	478	549	593			
" "	100	180.1	204.2	291	373	443	503	531			
Ammonium hydroxide	0	(238)	(271)	(404)	(526)	(647)	(764)	(908)	(1141)	–	(1406)
	10	9.66	–	–	–	23.2	–	22.3	15.6		
	30	5.66	–	–	–	13.6	–	13.0			
	100	3.10	3.62	5.35	6.70	7.47	–	7.17	4.82	–	1.33

* These values are at the concentration 80.0.

THE EQUIVALENT CONDUCTIVITY OF SOME ADDITIONAL SALTS IN AQUEOUS SOLUTION

Conditions similar to those of the preceding table except that the atomic weights for 1908 were used.

Substance.	Concentration.	Equivalent conductance at the following C° temperature.							
		0°	18°	25°	50°	75°	100°	128°	156°
Potassium nitrate . . .	0	80.8	126.3	145.1	219	299	384	485	580
" " . . .	2	78.6	122.5	140.7	212.7	289.9	370.3	460.7	551
" " . . .	12.5	75.3	117.2	134.9	202.9	276.4	351.5	435.4	520.4
" " . . .	50	70.7	109.7	126.3	189.5	257.4	326.1	402.9	476.1
" " . . .	100	67.2	104.5	120.3	180.2	244.1	308.5	379.5	447.3
Potassium oxalate . . .	0	79.4	127.6	147.5	230	322	419	538	653
" " . . .	2	74.9	119.9	139.2	215.9	300.2	389.3	489.1	587
" " . . .	12.5	69.3	111.1	129.2	199.1	275.1	354.1	438.8	524.3
" " . . .	50	63	101	116.5	178.6	244.9	312.2	383.8	449.5
" " . . .	100	59.3	94.6	109.5	167	227.5	288.9	353.2	409.7
" " . . .	200	55.8	88.4	102.3	155	210.9	265.1	321.9	372.1
Calcium nitrate . . .	0	70.4	112.7	130.6	202	282	369	474	575
" " . . .	2	66.5	107.1	123.7	191.9	266.7	346.5	438.4	529.8
" " . . .	12.5	61.6	98.6	114.5	176.2	244	314.6	394.5	473.7
" " . . .	50	55.6	88.6	102.6	157.2	216.2	276.8	343	405.1
" " . . .	100	51.9	82.6	95.8	146.1	199.9	255.5	315.1	369.1
" " . . .	200	48.3	76.7	88.8	135.4	184.7	234.4	288	334.7
Potassium ferrocyanide .	0	98.4	159.6	185.5	288	403	527		
" " .	0.5	91.6	–	171.1					
" " .	2.	84.8	137	158.9	243.8	335.2	427.6		
" " .	12.5	71	113.4	131.6	200.3	271	340		
" " .	50	58.2	93.7	108.6	163.3	219.5	272.4		
" " .	100	53	84.9	98.4	148.1	198.1	245		
" " .	200	48.8	77.8	90.1	135.7	180.6	222.3		
" " .	400	45.4	72.1	83.3	124.8	165.7	203.1		
Barium ferrocyanide . .	0	91	150	176	277	393	521		
" " . .	2	46.9	75	86.2	127.5	166.2	202.3		
" " . .	12.5	30.4	48.8	56.5	83.1	107	129.8		
Calcium ferrocyanide .	0	88	146	171	271	386	512		
" " . .	2	47.1	75.5	86.2	130				
" " . .	12.5	31.2	49.9	57.4					
" " . .	50	24.1	38.5	44.4	64.6	81.9			
" " . .	100	21.9	35.1	40.2	58.4	73.7	84.3		
" " . .	200	20.6	32.9	37.8	55	68.7	77.5		
" " . .	400	20.2	32.2	37.1	54	67.5	76.2		
Potassium citrate . . .	0	76.4	124.6	144.5	228	320	420		
" " . . .	0.5	–	120.1	139.4					
" " . . .	2	71	115.4	134.5	210.1	293.8	381.2		
" " . . .	5	67.6	109.9	128.2	198.7	276.5	357.2		
" " . . .	12.5	62.9	101.8	118.7	183.6	254.2	326		
" " . . .	50	54.4	87.8	102.1	157.5	215.5	273		
" " . . .	100	50.2	80.8	93.9	143.7	196.5	247.5		
" " . . .	300	43.5	69.8	81	123.5	167	209.5		
Lanthanum nitrate . .	0	75.4	122.7	142.6	223	313	413	534	651
" " . .	2	68.9	110.8	128.9	200.5	279.8	363.5	457.5	549
" " . .	12.5	61.4	98.5	114.4	176.7	243.4	311.2	383.4	447.8
" " . .	50	54	86.1	99.7	152.5	207.6	261.4	315.8	357.7
" " . .	100	49.9	79.4	91.8	139.5	189.1	236.7	282.5	316.3
" " . .	200	46	72.1	83.5	126.4	170.2	210.8	249.6	276.2

From the investigations of Noyes and Johnston, Journal of the American Chemical Society, 31, p. 287, 1909.

TABLE 511.—The Equivalent Conductivity of the Separate Ions

Ion.	0°	18°	25°	50°	75°	100°	128°	156°
K	40.4	64.6	74.5	115	159	206	263	317
Na	26	43.5	50.9	82	116	155	203	249
NH_4	40.2	64.5	74.5	115	159	207	264	319
Ag	32.9	54.3	63.5	101	143	188	245	299
$\frac{1}{2}$Ba	33	55^2	65	104	149	200	262	322
$\frac{1}{2}$Ca	30	51^2	60	98	142	191	252	312
$\frac{1}{3}$La	35	61	72	119	173	235	312	388
Cl	41.1	65.5	75.5	116	160	207	264	318
NO_3	40.4	61.7	70.6	104	140	178	222	263
$C_2H_3O_2$	20.3	34.6	40.8	67	96	130	171	211
$\frac{1}{2}SO_4$	41	68^2	79	125	177	234	303	370
$\frac{1}{2}C_2O_4$	39	63^2	73	115	163	213	275	336
$\frac{1}{3}C_6H_5O_7$	36	60	70	113	161	214		
$\frac{1}{4}Fe(CN)_6$	58	95	111	173	244	321		
H	240	314	350	465	565	644	722	777
OH	105	172	192	284	360	439	525	592

From Johnson, Journ. Amer. Chem. Soc., 31, p. 1010, 1909.

TABLE 512.—Hydrolysis of Ammonium Acetate and Ionization of Water

Temperature.	Percentage hydrolysis.	Ionization constant of water.	Hydrogen-ion concentration in pure water. Equivalents per liter.
t	100_h	$K_W \times 10^{14}$	$C_H \times 10^7$
0	–	0.089	0.30
18	(0.35)	0.46	0.68
25	–	0.82	0.91
100	4.8	48.	6.9
156	18.6	223.	14.9
218	52.7	461.	21.5
306	91.5	168.	13.0

Noyes, Kato, Kanolt, Sosman, No. 63 Publ. Carnegie Inst., Washington.

DIELECTRIC STRENGTH

TABLE 513.—Steady Potential Difference in Volts required to produce a Spark in Air with Ball Electrodes

Spark length. cm.	$R = 0$ Points.	$R = 0.25$ cm.	$R = 0.5$ cm.	$R = 1$ cm.	$R = 2$ cm.	$R = 3$ cm.	$R = \infty$ Plates.
0.02	–	–	1560	1530			
0.04	–	–	2460	2430	2340		
0.06	–	–	3300	3240	3060		
0.08	–	–	4050	3990	3810		
0.1	3720	5010	4740	4560	4560	4500	4350
0.2	4680	8610	8490	8490	8370	7770	7590
0.3	5310	11140	11460	11340	11190	10560	10650
0.4	5970	14040	14310	14340	14250	13140	13560
0.5	6300	15990	16950	17220	16650	16470	16320
0.6	6840	17130	19740	20070	20070	19380	19110
0.8	8070	18960	23790	24780	25830	26220	24960
1.0	8670	20670	26190	27810	29850	32760	30840
1.5	9960	22770	29970	37260			
2.0	10140	24570	33060	45480			
3.0	11250	28380					
4.0	12210	29580					
5.0	13050						

Based on the results of Baille, Bichat-Blondot, Freyburg, Liebig, Macfarlane, Orgler, Paschen, Quincke, de la Rue, Wolff. For spark lengths from 1 to 200 wave-lengths of sodium light, see Earhart, Phys. Rev. 15, p. 163; Hobbs, Phil. Mag. 10, p. 607, 1905.

TABLE 514.—Alternating Current Potential required to produce a Spark in Air with various Ball Electrodes

The potentials given are the maxima of the alternating waves used. Frequency, 33 cycles per second.

Spark length. cm.	$R = 1$ cm.	$R = 1.92$	$R = 5$	$R = 7.5$	$R = 10$	$R = 15$
0.08	3770					
.10	4400	4380	4330	4290	4245	4230
.15	5990	5940	5830	5790	5800	5780
.20	7510	7440	7340	7250	7320	7330
.25	9045	8970	8850	8710	8760	8760
0.30	10480	10400	10270	10130	10180	10150
.35	11980	11890	11670	11570	11610	11590
.40	13360	13300	13100	12930	12980	12970
.45	14770	14700	14400	14290	14330	14320
.50	16140	16070	15890	15640	15690	15690
0.6	18700	18730	18550	18300	18350	18400
.7	21350	21380	21140	20980	20990	21000
.8	23820	24070	23740	23490	23540	23550
0.9	26190	26640	26400	26130	26110	26090
1.0	28380	29170	28950	28770	28680	28610
1.2	32400	34100	33790	33660	33640	33620
1.4	35850	38850	38850	38580	38620	38580
1.6	38750	43400	43570	43250	43520	
1.8	40900	–	48300	47900		
2.0	42950	–	–	52400		

Based upon the results of Kawalski, Phil. Mag. 18, p. 699, 1909.

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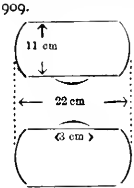
TABLE 515.—Potential Necessary to produce a Spark in Air between more widely Separated Electrodes

Spark length, cm.	Dull points. Alternating current.	Steady potentials. Ball electrodes. R=1 cm.	Steady potentials. Ball electrodes. R=2.5 cm.	Steady potentials. Cup electrodes. Projection. 4.5 mm.	Steady potentials. Cup electrodes. Projection. 1.5 mm.	Spark length, cm.	Dull points. Alternating current.	Steady potentials. Ball electrodes. R=1 cm.	Steady potentials. Ball electrodes. R=2.5 cm.
0.3	–	–	–	–	11280	6.0	61000	–	86830
0.5	–	17610	17620	–	17420	7.0	–	52000	–
0.7	–	–	23050	–	22950	8.0	67000	52400	90200
1.0	12000	30240	31390	31400	31260	10.0	73000	74300	91930
1.2	–	33800	36810	–	36700	12.0	82600	–	93300
1.5	–	37930	44310	–	44510	14.0	92000	–	94400
2.0	29200	42320	56000	56500	56530	15.0	–	–	94700
2.5	–	45000	65180	–	68720	16.0	101000	–	101000
3.0	40000	46710	71200	80400	81140	20.0	119000		
3.5	–	–	75300	–	92400	25.0	140600		
4.0	48500	49100	78600	101700	103800	30.0	165700		
4.5	–	–	81540	–	114600	35.0	190900		
5.0	56500	50310	83800	–	126500				
5.5	–	–	–	–	135700				

This table for longer spark lengths contains the results of Voege, Ann. der Phys. 14, 1904, using alternating current and "dull point" electrodes, and the results with steady potential found in the recent very careful work of C. Müller, Ann. d. Phys. 28, p. 585, 1909.



The specially constructed electrodes for the columns headed "cup electrodes" had the form of a projecting knob 3 cm in diameter and having a height of 4.5 mm and 1.5 mm respectively, attached to the plane face of the electrodes. These electrodes give a very satisfactory linear relation between the spark lengths and the voltage throughout the range studied.

TABLE 516.—Effect of the Pressure of the Gas on the Dielectric Strength

Voltages are given for different spark lengths *l*.

Pressure. cm Hg	l=0.04	l=0.06	l=0.08	l=0.10	l=0.20	l=0.30	l=0.40	l=0.50
2	–	–	–	–	744	939	1110	1266
4	–	483	567	648	1015	1350	1645	1915
6	–	582	690	795	1290	1740	2140	2505
10	–	771	933	1090	1840	2450	3015	3580
15	–	1060	1280	1490	2460	3300	4080	4850
25	1110	1420	1725	2040	3500	4800	6000	7120
35	1375	1820	2220	2615	4505	6270	7870	9340
45	1640	2150	2660	3120	5475	7650	9620	11420
55	1820	2420	3025	3610	6375	8950	11290	13455
65	2040	2720	3400	4060	7245	10210	12950	15470
75	2255	3035	3805	4565	8200	11570	14650	17450

This table is based upon the results of Orgler, 1899. See this paper for work on other gases (or Landolt-Börnstein-Meyerhoffer).

For long spark lengths in various gases see Voege, Electrotechn. Z. 28, 1907. For dielectric strength of air and CO_2 in cylindrical air condensers, see Wien, Ann. d. Phys. 29, p. 679, 1909.

Tables 517 and 518

DIELECTRIC STRENGTH

TABLE 517.—Dielectric Strength of Materials

Potential necessary for puncture expressed in kilovolts per centimeter thickness of the dielectric.

Substance.	Kilovolts per cm	Substance.	Kilovolts per cm.	Substance.	Kilovolts per cm.
Ebonite	300–1100	Oils: Thickness		Papers:	
Empire cloth	80–300	Castor 0.2 mm	190	Beeswaxed	770
" paper	450	" 1.0 "	130	Blotting	150
Fibre	20	Cottonseed	70	Manilla	25
Fuller board	200–300	Lard 0.2 "	140	Paraffined	500
Glass	300–1500	" 1.0 "	40	Varnished	100–250
Granite (fused)	90	Linseed, raw 0.2 "	185	Paraffine:	
Guttapercha	80–200	" " 1.0 "	90	Melted	75
Impregnated jute	20	" boiled 0.2 "	190	Melt point.	
Leatheroid	30–60	" " 1.0 "	80	Solid 43°	350
Linen, varnished	100–200	Lubricating	50	" 47°	400
Liquid air	40–90	Neatsfoot 0.2 "	200	" 52°	230
Mica: Thickness.		" 1.0 "	90	" 70°	450
Madras 0.1 mm	1600	Olive 0.2 "	170	Presspaper	45–75
" 1.0 "	300	" 1.0 "	75	Rubber	160–500
Bengal 0.1 "	2200	Paraffin 0.2 "	215	Vaseline	90–130
" 1.0 "	700	" 1.0 "	160	Thickness.	
Canada 0.1 "	1500	Sperm, mineral 0.2 "	180	Xylene 0.2 mm	140
" 1.0 "	500	" " 1.0 "	85	" 1.0 "	80
South America	1500	" natural 0.2 "	195		
Micanite	400	" " 1.0 "	90		
		Turpentine 0.2 "	160		
		" 1.0 "	110		

TABLE 518.—Potentials in Volts to Produce a Spark in Kerosene

Spark length. mm.	Electrodes Balls of Diam. *d*.			
	0.5 cm.	1 cm.	2 cm.	3 cm.
0.1	3800	3400	2750	2200
.2	7500	6450	4800	3500
.3	10250	9450	7450	4600
.4	11750	10750	9100	5600
.5	13050	12400	11000	6900
.6	14000	13550	12250	8250
.8	15500	15100	13850	10450
1.0	16750	16400	15250	12350

Determinations of the dielectric strength of the same substance by different observers do not agree well. For a discussion of the sources of error see Mościcki, Electrotechn. Z. 25, 1904.

For more detailed information on the dependence of the sparking distance in oils as a function of the nature of the electrodes, see Edmondson, Phys. Review 6, p. 65, 1898.

TABLE 519.—Dielectric Constant (Specific Inductive Capacity) of Gases

Atmospheric Pressure
Wave lengths of the measuring current greater than 10000 cm

Gas	°C	Dielectric constant		Ref.	Gas	°C	Dielectric constant		Ref.
		Vacuum = 1	Air = 1				Vacuum = 1	Air = 1	
Air	0	1.000588	1.000000	(1)	HCl	100	1.00258	1.00199	(2)
NH_3	20	1.00718	1.00659	(2)	H_2	0	1.000264	.999676	(1)
CS_2	0	1.00290	1.00231	(3)	CH_4	0	1.000948	1.000360	(2)
"	100	1.00239	1.00180	(2)	N_2O	0	1.00108	1.00050	(1)
CO_2	0	1.000966	1.000377	(1)	SO_2	0	1.00993	1.00934	(2)
CO	0	1.000692	1.000104	(1)	H_2O, 4 atm.	145	1.00705	1.00646	(2)
C_2H_4	0	1.00138	1.00079	(1)					

(1) Mean. (2) Bädeker, 1901. (3) Klemenčič, 1885.

TABLE 520.—Variation of the Dielectric Constant with the Temperature

If ϵ_θ = the dielectric constant at the temperature θ°C of the above table, ϵ_t at the temperature t°C, and α and β are quantities in the following table, then $\epsilon_t = \epsilon_\theta - \alpha (t - \theta) + \beta (t - \theta)^2$.

Ammonia	$\alpha = 5.45 \times 10^{-5}$	$\beta = 2.59 \times 10^{-7}$	Range, 15–110°C
Sulphur dioxide	6.19×10^{-5}	1.86×10^{-7}	0–110
Water vapor	1.4×10^{-4}	....	145

The dielectric constant of air at 76 cm and varying temperature may be calculated since D − 1 is approximately proportional to the density.

TABLE 521.—Variation of the Dielectric Constant of Gases with the Pressure

	°C	Pressure atm.				°C	Pressure atm.		
Air	19	20	1.0108	(1)	Air	11	120	1.0579	(2)
"	"	40	1.0218	(1)	"	"	140	1.0674	(2)
"	"	60	1.0330	(1)	"	"	160	1.0760	(2)
"	"	80	1.0439	(1)	"	"	180	1.0845	(2)
"	"	100	1.0548	(1)	CO_2	15	10	1.008	(3)
"	11	20	1.0101	(2)	"	"	20	1.020	(3)
"	"	40	1.0196	(2)	"	"	40	1.060	(3)
"	"	60	1.0294	(2)	N_2O	15	10	1.010	(3)
"	"	80	1.0387	(2)	"	"	20	1.025	(3)
"	"	100	1.0482	(2)	"	"	40	1.070	(3)

(1) Tangl, 1907. (2) Occhialini, 1905. (3) Linde, 1895.

TABLE 522.—Dielectric Constant of Liquids (ε). Pressure Effect

(Danforth, Phys. Rev., 38, 1224, 1931.)

	P atm.	30°C ε	30°C Density	75°C ε	75°C Density
C_5H_{12}	1	1.82	0.613	. . . .	. . . .
Pentane	1000	1.96	.701	1.92	. . . .
	4000	2.12	.796	2.11	. . . .
	8000	2.24	.865	2.22	. . . .
	12000	2.33	.907	2.31	. . . .
CS_2	1	2.61	1.241	. . . .	. . . .
Carbon	1000	2.82	1.332	2.69	1.29
bisulphide	4000	3.11	1.487	3.02	1.46
	8000	3.33	1.601	3.28	1.58
	12000	3.52	1.689	3.45	1.66
$(C_2H_5)_2O$	1	4.15	.720	. . . .	. . . .
Ethyl	1000	4.88	.801	4.08	.74
ether	4000	6.05	.911	5.17	.87
	8000	6.93	.988	6.00	.94
	12000	7.68	1.047	6.94	1.00
C_6H_5Br	1	5.22	1.465	4.87	1.40
Bromo-	500	5.36	1.525	5.05	1.46
benzene	1000	5.47	1.558	5.16	1.50
	4000	5.88	1.705	5.62	1.65
	8000	. . . .	. . . .	5.95	1.76
C_6H_5Cl	1	5.41	1.004	4.90	.96
Chloro-	500	5.59	1.038	5.12	1.00
benzene	1000	5.75	1.065	5.28	1.03
	4000	6.33	1.152	5.88	1.13
	8000	. . . .	. . . .	6.29	1.20
$C_6H_{13}OH$	1	12.90	.812	8.55	.78
Hexyl	1000	13.54	.861	9.32	.84
alcohol	4000	15.06	.937	10.42	.92
	8000	. . . .	. . . .	11.15	.99

	P atm.	0°C ε	0°C Density	30°C ε	30°C Density
C_2H_5OH	1	27.8	0.806	23.2	0.781
Ethyl	1000	29.4	.864	25.3	.844
alcohol	8000	35.3	1.031	31.7	1.019
	12000	57.6	1.082	33.7	1.073
C_4H_9OH	1	21.1	.819	17.3	.806
i-butyl	1000	22.9	.877	18.7	.856
alcohol	8000	26.8	1.031	22.8	1.018
	12000	28.2	1.080	23.9	1.069
$C_3H_8O_3$	1	49.9	1.272	42.8	1.254
Glycerine	1000	51.9	1.305	44.8	1.287
	4000	56.4	1.367	49.1	1.349
	8000	61.1	1.429	53.8	1.410

Anomalous dispersion 247000 cycles

Isobutyl-alcohol: 0°C						
p:	1	2900	5810	9680	10830	12130
ε:	21.1	24.4	25.9	27.4	27.2	26.4
Glycerine . . P		1	1940	4290	6330	8490
0°C . . . . ε		49.9	53.4	55.6	52.2	40.1
Eugenol . . . . P		1	2960	5081	5680	6300
30°C . . . . ε		9.42	10.79	11.09	10.57	6.05

TABLE 523.—Dielectric Constant of Liquids

A wave length greater than 10000 centimeters is denoted by ∞.

Substance	Temp. °C.	Wave-length, cm.	Dielectric constant.	Author-ity.	Substance.	Temp. °C.	Wave-length, cm.	Dielectric constant.	Author-ity.
Alcohol:					Alcohol:				
Amyl . . .	frozen	∞	2.4	1	Methyl . .	−50	∞	45.3	1
" . . .	−100	"	30.1	1	" . . .	0	"	35.0	1
" . . .	−50	"	23.0	1	" . . .	+20	"	31.2	1
" . . .	0	"	17.4	1	" . . .	17	75	33.2	2
" . . .	+20	"	16.0	1	Propyl . .	−120	∞	46.2	1
" . . .	18	200	10.8	2	" . . .	−60	"	33.7	1
" . . .	18	73	4.7	2	" . . .	0	"	24.8	1
Ethyl . . .	frozen	∞	2.7	1	" . . .	+20	"	22.2	1
" . . .	−120	"	54.6	1	" . . .	15	75	12.3	2
" . . .	−80	"	44.3	1	Acetone . . .	−80	∞	33.8	5
" . . .	−40	"	35.3	1	" . . .	0	"	26.6	5
" . . .	0	"	28.4	1	" . . .	15	1200	21.85	6
" . . .	+20	"	25.8	1	" . . .	17	73	20.7	7
" . . .	17	200	24.4	2	Acetic acid .	18	∞	9.7	8
" . . .	"	75	23.0	2	" " . .	15	1200	10.3	6
" . . .	"	53	20.6	3	" " . .	17	200	7.07	2
" . . .	"	4	8.8	3	" " . .	19	75	6.29	2
" . . .	"	0.4	5.0	4	Amyl acetate .	19	∞	4.81	9
Methyl . .	frozen	∞	3.07	1	Amylene . .	16	"	2.20	10
" . . .	−100	"	58.0	1					

References on page 444

Table 523 (*continued*)

DIELECTRIC CONSTANT OF LIQUIDS

A wave length greater than 10000 centimeters is designated by ∞.

Substance.	Temp. °C.	Wave-length cm.	Diel. const.	Authority.
Aniline	18	∞	7.316	11
Benzol (benzene)	18	"	2.288	"
" "	19	73	2.26	2
Bromine	23	84	3.18	12
Carbon bisulphide	20	∞	2.626	13
" "	17	73	2.64	2
Chloroform	18	∞	5.2	11
"	17	73	4.95	2
Decane	14	∞	1.97	10
Decylene	17	"	2.24	"
Ethyl ether	−80	∞	7.05	5
" "	−40	"	5.67	"
" "	0	"	4.68	"
" "	18	"	4.368	11
" "	20	"	4.30	13
" "	60	"	3.65	"
" "	100	"	3.12	"
" "	140	"	2.66	"
" "	180	"	2.12	"
" "	Crit. temp 192	"	1.53	"
" "	18	83	4.35	14
Formic acid	+2 (frozen)	73	19.0	2
" "	15	1200	62.0	6
" "	16	73	58.5	2
Glycerine	15	1200	56.2	6
"	15	200	39.1	2
"	15	75	25.4	"
"	–	8.5	4.4	15
"	–	0.4	2.6	4
Hexane	17	∞	1.880	16
Hydrogen peroxide 46% in H_2O	18	75	84.7	17

Substance.	Temp. °C.	Wave-length cm.	Diel. const.	Authority.
Nitrobenzol	(frozen) −10	∞	9.9	1
"	−5	"	42.0	"
"	0	"	41.0	"
"	+15	"	37.8	"
"	30	"	35.1	"
"	18	"	36.45	11
"	17	73	34.0	2
Octane	17	∞	1.949	16
Oils:				
Almond	20	∞	2.83	18
Castor	11	"	4.67	19
Colza	20	"	3.11	20
Cottonseed	14	"	3.10	21
Lemon	21	"	2.25	22
Linseed	13	"	3.35	21
Neatsfoot	–	"	3.02	20
Olive	20	"	3.11	23
Peanut	11.4	"	3.03	21
Petroleum	–	2000	2.13	24
Petroleum ether	20	∞	1.92	20
Rape seed	16	"	2.85	21
Sesame	13.4	"	3.02	"
Sperm	20	"	3.17	20
Turpentine	20	"	2.23	"
Vaseline	–	"	2.17	25
Phenol	48	73	9.68	2
Toluene	−83	∞	2.51	5
"	+16	"	2.33	"
"	19	73	2.31	2
Meta-xylene	18	∞	2.376	11
" "	17	73	2.37	2
Water	18	∞	81.07	11
for temp. coeff.	17	200	80.6	2
see Table 524.	17	74	81.7	"
	17	38	83.6	"

1 Abegg-Seitz, 1899.
2 Drude, 1896.
3 Marx, 1898.
4 Lampa, 1896.
5 Abegg, 1897.
6 Thwing, 1894.
7 Drude, 1898.
8 Francke, 1893.
9 Löwe, 1898.
10 Landolt-Jahn, 1892.
11 Turner, 1900.
12 Schlundt.
13 Tangl, 1903.
14 Coolidge, 1899.
15 v. Lang, 1896.
16 Nernst, 1894.
17 Calvert, 1900.
18 Hasenöhrl, 1896.
19 Arons-Rubens, 1892.
20 Hopkinson, 1881.
21 Salvioni, 1888.
22 Tomaszewski, 1888.
23 Heinke, 1896.
24 Marx.
25 Fuchs.

DIELECTRIC CONSTANT OF LIQUIDS

TABLE 524.—Temperature Coefficients of the Formula:

$$D_\theta = D_t[1 - \alpha(t-\theta) + \beta(t-\theta)^2]$$

Substance.	α	β	Temp. range, ° C.	Authority.
Amyl acetate	0.0024	–	–	Löwe.
Aniline	0.00351	–	–	Ratz.
Benzene	0.00106	0.0000087	10–40	Hasenöhrl.
Carbon bisulphide	0.000966	–	–	Ratz.
" "	0.000922	0.00000060	20–181	Tangl.
Chloroform	0.00410	0.000015	22–181	"
Ethyl ether	0.00459	–	–	Ratz.
Methyl alcohol	0.0057	–	–	Drude.
Oils: Almond	0.00163	0.000026	–	Hasenöhrl.
Castor	0.01067	–	–	Heinke, 1896.
Olive	0.00364	–	–	" "
Paraffine	0.000738	0.0000072	–	Hasenöhrl.
Toluene	0.000921	–	0–13	Ratz.
"	0.000977	0.00000046	20–181	Tangl.
Water	0.004474	–	5–20	Heerwagen.
"	0.004583	0.0000117	0–76	Drude.
"	0.00436	–	4–25	Coolidge.
Meta-xylene	0.000817	–	20–181	Tangl.

(See Table 520 for the signification of the letters.)

TABLE 525.—Dielectric Constant of Liquefied Gases

A wave-length greater than 10000 centimeters is designated by ∞.

Substance.	Temp. ° C.	Wave-length cm.	Diel. constant.	Authority.	Substance.	Temp. ° C.	Wave-length cm.	Diel. constant	Authority.
Air	−191	∞	1.432	1	Nitrous oxide				
"	"	75	1.47–1.50	2	N_2O	−88	∞	1.938	8
Ammonia	−34	75	21–23	3	" "	−5	"	1.630	5
"	14	130	16.2	4	" "	+5	"	1.573	"
Carbon dioxide	−5	∞	1.608	5	" "	+15	"	1.520	"
" "	0	"	1.583	"	Oxygen	−182	"	1.491	9
" "	+10	"	1.540	"	"	"	"	1.465	8
" "	+15	"	1.526	"	Sulphur dioxide	14.5	120	13.75	4
Chlorine	−60	"	2.150	"	" "	20	∞	14.0	6
"	−20	"	2.030	"	" "	40	"	12.5	"
"	0	"	1.970	"	" "	60	"	10.8	"
"	+10	"	1.940	"	" "	80	"	9.2	"
"	0	"	2.08	6	" "	100	"	7.8	"
"	+14	100	1.88	4	" "	120	"	6.4	"
Cyanogen	23	84	2.52	7	" "	140	"	4.8	"
Hydrocyanic acid	21	"	about 95	"	Critical	154.2	"	2.1	"
Hydrogen sulph.	10	∞	5.93	6					
" "	50	"	4.92	"					
" "	90	"	3.76	"					

1 v. Pirani, 1903.
2 Bahn-Kiebitz, 1904.
3 Goodwin-Thompson, 1899.
4 Coolidge, 1899.
5 Linde, 1895.
6 Eversheim, 1904.
7 Schlundt. 1901.
8 Hasenöhrl, 1900.
9 Fleming-Dewar, 1896.

DIELECTRIC CONSTANT

TABLE 526.—Standard Solutions for the Calibration of Apparatus for the Measuring of Dielectric Constant

Turner.

Substance.	Diel. const. at 18°. $\lambda = \infty$.
Benzene	2.288
Meta-xylene	2.376
Ethyl ether	4.36^{7}
Aniline	7.29^{8}
Ethyl chloride . . .	10.90
O-nitro toluene . .	27.71
Nitrobenzene . . .	36.45
Water (conduct. 10^{-6})	81.07

Drude.

Per cent by weight.	Density 16°.	Dielectric constant.	Temp. coefficient.
Acetone in benzene at 19°. $\lambda = 75$ cm.			
0	0.885	2.26	0.1%
20	0.866	5.10	0.3
40	0.847	8.43	0.4
60	0.830	12.1	0.5
80	0.813	16.2	0.5
100	0.797	20.5	0.6
Water in acetone at 19°. $\lambda = 75$ cm.			
0	0.797	20.5	0.6%
20	0.856	31.5	0.5
40	0.903	43 5	0.5
60	0.940	57.0	0.5
80	0.973	70.6	0.5
100	0.999	80.9	0.4

Nernst.

Ethyl alcohol in water at 19.5°. $\lambda = \infty$.	
Per cent by weight.	Dielectric constant.
100	26.0
90	29.3
80	33.5
70	38.0
60	43.1

TABLE 527.—Dielectic Constant of Solids

Substance.	Condition.	Wave-length, cm.	Dielectric constant.	Authority.
Asphalt . .	–	∞	2.68	1
Barium sulphate . .	–	75	10.2	2
Caoutchouc .	–	∞	2.22	3
Diamond . .	–	"	16.5	1
" . .	–	75	5.50	2
Ebonite . .	–	∞	2.72	4
" . .	–	"	2.86	5
" . .	–	1000	2.55	6
Glass *	Density.			
Flint (extra heavy) .	4.5	∞	9.90	7
Flint (very light) . .	2.87	"	6.61	7
Hard crown	2.48	"	6.96	7
Mirror . .	–	"	6.44–7.46	5
" . .	–	"	5.37–5.90	8
" . .	–	600	5.42–6.20	8
Lead (Powell) . . .	3.0–3.5	∞	5.4–8.0	9
Jena				
Boron .	–	"	5.5–8.1	10
Barium .	–	"	7.8–8.5	10
Borosilicate .	–	"	6.4–7.7	1
Gutta percha .	–	–	3.3–4.9	11
	Temp.			
Ice	—5	1200	2.85	12
"	—18	5000	3.16	13
"	—190	75	1.76–1.88	14

Substance.	Condition.	Wave-length, cm.	Dielectric constant.	Authority.
	Temp.			
Iodine (cryst.) .	23	75	4.00	2
Lead chloride . (powder)	–	"	42	2
" nitrate .	–	"	16	2
" sulphate .	–	"	28	2
" molybdenate . .	–	"	24	2
Marble (Carrara)	–	"	8.3	2
Mica	–	∞	5.66–5.97	5
"	–	"	5.80–6.62	15
Madras, brown	–	"	2.5–3.4	16
" green	–	"	3.9–5.5	16
" ruby .	–	"	4.4	16
Bengal, yellow	–	"	2.8	16
" white .	–	"	4.2	16
" ruby .	–	"	4.2–4.7	16
Canadian amber	–	"	3.0	16
South America	–	"	5.9	16
Ozokerite (raw)	–	"	2.21	1
Paper (telephone)	–	"	2.0	17
" (cable) .	–	"	2.0–2.5	1
	Melting point.			
Paraffine . . .		"	2.46	18
" . . .		"	2.32	19
" . . .	44–46	"	2.10	20
" . . .	54–56	"	2.14	20
" . . .	74–76	"	2.16	20

References on p. 447.

* For the effect of temperature, see Gray-Dobbie, Pr. Roy. Soc. 63, 1898; 67, 1900.
" " " " wave-length, see K. F. Löwe, Wied. Ann. 66, 1898.

TABLE 527 (*continued*).—Dielectric Constant of Solids

Substance.	Condition.	Wave-length, cm.	Diel. constant.	Authority.
Paraffine	47.°6	61	2.16	21
"	56.°2	61	2.25	21
Phosphorus:				
Yellow	–	75	3.60	2
Solid	–	80	4.1	22
Liquid	–	80	3.85	22
Porcelain:				
Hard				
(Royal B'l'n)	–	∞	5.73	15
Seger " "	–	"	6.61	15
Figure " "	–	"	6.84	15
Selenium	–	"	7.44	1
"	–	75	6.60	2
"	–	∞	6.13	23
"	–	1000	6.14	23
Shellac	–	∞	3.10	4
"	–	"	2.95–3.73	24
"	–	"	3.67	25
Amber	–	–	**2.86**	18

Substance.	Condition.	Wave-length, cm.	Diel. constant.	Authority.
Sulphur				
Amorphous	–	∞	3.98	1
"	–	75	3.80	2
Cast, fresh	–	∞	4.22	1
" "	–	"	4.05	18
" "	–	75	3.95	2
Cast, old	–	∞	3.60	18
" "	–	75	3.90	2
Liquid	near melting-point	∞	3.42	1
Strontium sulphate	–	75	11.3	2
Thallium carbonate	–	75	17	2
" nitrate	–	75	16.5	2
Wood			dried	
Red beech	‖ fibres	∞	4.83–2.51	–
" "	⊥ "	"	7.73–3.63	–
Oak	‖ "	"	4.22–2.46	–
"	⊥ "	"	6.84–3.64	–

1 v. Pirani, 1903.
2 Schmidt, 1903.
3 Gordon, 1879.
4 Winklemann, 1889.
5 Elsas, 1891.
6 Ferry, 1897.
7 Hopkinson, 1891.
8 Arons-Rubens, 1891.
9 Gray-Dobbie, 1898.
10 Löwe, 1898.
11 (submarine-data).
12 Thwing, 1894.
13 Abegg, 1897.
14 Behn-Kiebitz, 1904.
15 Starke, 1897.
16 E. Wilson.
17 Campbell, 1906.
18 Fallinger, 1902.
19 Boltzmann, 1875.
20 Zietkowski, 1900.
21 Hormell, 1902.
22 Schlundt, 1904.
23 Vonwiller-Mason, 1907.
24 Wüllner, 1887.
25 Donle.

TABLE 528.—Dielectric Constant of Crystals

Dα, Dβ, Dγ are the dielectric constants along the brachy, macro and vertical axes respectively.

Substance.	Wave-length, cm.	Diel. const. ⊥ Axis.	Diel. const. ‖ Axis.	Authority.
UNIAXIAL:				
Apatite	75	9.50	7.40	1
Beryl	∞	7.85	7.44	2
"	"	7.10	6.05	3
"	75	6.05	5.52	1
Calcite	∞	8.49	7.56	4
"	"	8.78	8.29	5
Dolomite	75	7.80	6.80	1
Iceland spar	75	8.50	8.00	1
Quartz	∞	4.69	5.06	4
"	"	4.38	4.46	6
"	1000	4.27	4.34	6
Ruby (Siam)	–	13.3	11.3	4
Rutile (TiO_2)	75	89	1.73	1
Tourmaline	∞	7.13	6.54	4
"	75	6.75	5.65	1
Zircon	75	12.8	12.6	1

Substance.	Wave-length, cm.	Diel. const. Dα	Dβ	Dγ	Authority.
RHOMBIC:					
Aragonite	∞	9.14	–	7.13	4
"	75	9.80	7.68	6.55	1
Barite	∞	6.97	10.09	7.00	4
"	75	7.65	12.20	7.70	1
Celestite	75	7.70	18.5	8.30	1
Cerussite	75	25.4	23.2	19.2	1
$MgSO_4+7H_2O$	∞	5.26	6.05	8.28	7
K_2SO_4	"	6.09	5.08	4.48	7
Rochelle salt*	"	6.70	6.92	8.89	7
Sulphur	"	3.81	3.97	4.77	8
"	"	3.65	3.85	4.66	7
"	75	3.62	3.85	4.66	1
Topaz	75	6.65	6.70	6.30	1
" colorless	–	6.25	6.54	6.44	4

* See page 448.

1 Schmidt, 1903.
2 Starke, 1897.
3 Curie, 1889.
4 Fallinger, 1902, 1919.
5 v. Pirani, 1903.
6 Ferry, 1897.
7 Borel, 1893.
8 Bolztmann, 1875.

ELECTROSTRICTION. PIEZO-ELECTRICITY

Electrostriction is a phenomenon observed when an isotropic dielectric is placed in an electrostatic field (F), the form and volume of the dielectric altering. Similar effects occur in anisotropic materials but are obscured by piezo-electric effects. Piezo-electricity occurs when a crystal dielectric is mechanically strained becoming electrically polarized. The magnitude and direction of the polarization (P) depends on the crystal used, the amount of strain and its direction relative to the axes of the crystal. Pyro-electricity is of the nature of a temperature-coefficient dp/dt. For fuller discussion and more extensive data see I.C.T., 6, 207, 1918 (Cody).

TABLE 529.—Electrostriction (Means)

	Glass	Paraffin	Ebonite	Rubber (vulcanized)	
$\Delta l/lE^2$	$.4 \times 10^{-12}$	90×10^{-12}	600×10^{-12}	6000×10^{-12}	$cm^2/c.g.s.e^2$

These values divided by 1.11×10^{-5} for values in $cm^2/volt^2$.

TABLE 530.—Piezo-electricity

Rochelle salt, $KNaC_4H_4O_6 \cdot 4H_2O$	$d_{14} =$	17	$\times 10^{-8}(es/cm^2)/(dyne/cm^2)$	$-70°$ C
" "		8100	"	+ 20
" "		1100	"	+ 30
" "		400	"	+ 40
Benzil, $C_{14}H_{10}O_2$	$d_{11} =$	24	"	....
$LiNa_3(MoO_4)_2 \cdot 6H_2O$	$d_{33} =$	14	"	....
Rb. tartrate, $Rb_2C_4H_4O_6$	$d_{11} =$	8	"	....
Tartaric acid, $C_4H_6O_6$	$d_{14} =$	−24	"	....
" "	$d_{15} =$	+28	"	....
" "	$d_{25} =$	−36	"	....
" "	$d_{31} =$	2.	"	....
" "	$d_{32} =$	6.	"	....
" "	$d_{33} =$	6.	"	....
" "	$d_{36} =$	4.	"	....
Tourmaline	$d_{33} =$	5.78	"	....
"	$d_{15} =$	11.0	"	....
"	$d_{22} =$	− 0.7	"	....
"	$d_{31} =$	0.7	"	....
Patchouli camphor, $C_{15}H_{26}O$	$d_{11} =$	.14	"	....
Diamond, C	..	0	"	....
Quartz, SiO_2	$d_{11} =$	− 6.9	"	....
Sodium chlorate, $NaClO_3$	$d_{14} =$	− 4.8	"	....
Fenchoneoxene, $C_{10}H_{17}NO$	$d_{33} =$	−10.2	"	....

Addenda to Table 528, p. 447, Dielectric Constant of Rochelle Salt:

The polarization of the Rochelle salt dielectric in an electric field is somewhat analagous to the behavior of the magnetization of iron in a magnetic field, showing both saturation and hysteresis. The dielectric constant D depends on the initial and final fields and the hysteresis.

Initial field, v/cm	Final field, v/cm	Average D (23° C)
765	690	40
765	−153	205
765	−765	157
0	880	86

The last value may be fair value for ordinary purposes. The electrodes were tinfoil attached with shellac. The field was applied perpendicular to the a axis. Like piezo-electric properties, the dielectric constant varies with different crystals. It depends on the temperature as follows: (field 0 to 880 v/cm)

$-70°$ C, D = 12; $-40°$, 14; $-20°$, 48; 0°, 174; $+20°$, 88; $+30°$, 52.

(Data from Valesek, University of Minnesota, 1921.)

THE CALCULATION OF THE HIGH-FREQUENCY RESISTANCE OF CONDUCTORS

(By Dr. F. W. Grover, Consulting Physicist, Bur. Standards, 1931.)

The resistance of a conductor to high frequency alternating currents is not the same as it offers to direct or low frequency currents. The linkages of flux with the inner portions of the conductor are more numerous than with the outer portions. That is, the reactances of the inner filaments are greater than those of the outer filaments. Consequently, the current density decreases from the outside toward the center of the conductor.

This tendency of the current to crowd toward the outer portions of the cross section becomes more pronounced the higher the frequency, and at very high frequencies the current density is sensibly zero everywhere except in the surface layer of the conductor. This phenomenon is called the "skin effect." It causes an increase in the effective resistance of the conductor over its resistance to a direct current.

What is of interest in the calculation of the high frequency resistance is the *resistance ratio,* the quotient of the resistance at the given frequency by the direct current resistance. The resistance ratio depends upon the distribution of current density in the cross section, and this is a function of the frequency and the shape of the cross section. In general, however, the resistance ratio is a function of the parameter $\frac{\sqrt{f}}{R_0}$, in which f is the frequency, and R_0 is the direct current resistance per unit length. In what follows R_0 will be taken as the direct current resistance per 1000 ft. of conductor.

The distribution of current in the cross section is affected by a neighboring conductor carrying high frequency currents. This *proximity effect* finds an explanation in that the value of the mutual inductance of any filament A of one conductor on a filament B of the other conductor depends upon the positions of A and B in their respective cross sections. The proximity effect may be very appreciable for conductors nearly in contact; falling off rapidly as their distance is increased, it is negligible for moderate ratios of distance apart to cross sectional dimensions. In such cases the resistance is sensibly the same as for an *isolated* conductor.

Beside the spacing factor of the conductors, the proximity effect depends upon the frequency, and in lesser degree upon the shape of the cross sections. Quantitatively, the proximity effect may be expressed by the *proximity factor,* which is the quotient of actual resistance of the conductor by the resistance which it would have if removed to a great distance from the disturbing conductor, both values of resistance being referred to the same frequency.

That is, if

$R_0 =$ the direct current resistance
$R_1 =$ the resistance of the conductor when isolated, frequency f
$R_2 =$ the resistance in the presence of the disturbing conductor at frequency f

then the proximity factor is $P = \frac{R_2}{R_1}$, and the resistance ratio $\frac{R_2}{R_0}$, in the presence of the disturbing conductor, is obtained from the resistance ratio $\frac{R_1}{R_0}$ when isolated by the relation $\frac{R_2}{R_0} = P\ \frac{R_1}{R_0}$. Resistance ratio may be obtained in any case if the resistance ratio when isolated is known, together with the value of the proximity factor.

Formulas for the high-frequency resistance ratio have been developed in only a few simple (but important) cases, and even then very complicated formulas result. For practical work tables are necessary for simplifying the calculations. The following tables cover the most important cases.

Formulas have been derived for the high-frequency resistance ratio of single-layer coils wound with round wire. Generally, these differ from one another and from measured values, because, simplifying assumptions are made which are not sufficiently realized in practice. No tables of values for coils such as are met in practical radio work are available. As a rough guide, the high-frequency resistance ratio for a single-layer coil is often from two to five times as great as the resistance ratio of the same wire stretched out straight and carrying current of the given frequency. The experimental work available indicates that this factor due to the coiling of the wire, that is, the total proximity effect of the turns of the coil, is largely dependent upon the frequency and the ratio of wire diameter to pitch of winding, and in lesser degree to the ratio of length to diameter.

(Calculated by Dr. F. W. Grover, Consulting Physicist, Bur. Standards, 1931.)

TABLE 532.—Resistance Ratio "F" for Isolated Round Wires

Resistance ratio F of isolated round wire, as a function of the square root of the frequency divided by the direct current resistance per 1000 ft. of conductor.

$\sqrt{f/R_0}$	0	10	20	30	40	50	60	70	80	90	100
F	1.000	1.000	1.0005	1.0025	1.008	1.019	1.038	1.069	1.114	1.173	1.247
$\sqrt{f/R_0}$	100	120	140	160	180	200	250	300	350	400	500
F	1.247	1.427	1.631	1.836	2.036	2.231	2.715	3.201	3.688	4.176	5.152

TABLE 533.—Values of Resistance Ratio for Isolated Tubular Conductors

t, thickness of wall of tube; d, outer diameter of tube.

$\sqrt{\frac{f}{R_0}}$ \ $\frac{t}{d}$ =	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
50	1.000	1.000	1.000	1.001	1.001	1.001	1.001	1.001	1.001	1.001
100	1.001	1.001	1.002	1.002	1.004	1.008	1.007	1.009	.....	1.014
150	1.001	1.003	1.006	1.011	1.017	1.024	1.033	1.044	1.056	1.070
200	1.002	1.008	1.019	1.034	1.053	1.076	1.104	1.134	1.167	1.204
250	1.005	1.020	1.046	1.081	1.125	1.176	1.233	1.296	1.365	1.440
300	1.011	1.042	1.095	1.163	1.25	1.34	1.44	1.55	1.65	1.75
350	1.020	1.076	1.167	1.285	1.42	1.56	1.70	1.83	1.97	2.09
400	1.032	1.127	1.27	1.44	1.66	1.81	1.99	2.13	2.28	2.42
450	1.051	1.198	1.41	1.63	1.87	2.08	2.28	2.44	2.60	2.74
500	1.079	1.30	1.57	1.86	2.14	2.34	2.56	2.73	2.88	3.03
$\sqrt{\frac{f}{R_0}}$ \ $\frac{t}{d}$ =	0.10	0.12	0.15	0.20	0.25	0.30	0.35	0.40	0.45	Solid 0.50
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
50	1.001	1.001	1.002	1.004	1.006	1.008	1.012	1.015	1.017	1.019
100	1.014	1.021	1.032	1.063	1.094	1.132	1.175	1.202	1.224	1.247
150	1.070	1.102	1.155	1.266	1.39	1.51	1.60	1.68	1.71	1.733
200	1.204	1.294	1.42	1.65	1.845	1.995	2.095	2.15	2.20	2.231
250	1.44	1.585	1.79	2.11	2.32	2.45	2.536	2.64	2.68	2.715
300	1.75	1.94	2.19	2.51	2.735	2.90	3.03	3.12	3.17	3.201
350	2.09	2.33	2.57	2.90	3.15	3.35	3.495	3.59	3.66	3.688
400	2.42	2.66	2.92	3.27	3.58	3.80	3.96	4.07	4.14	4.176
450	2.74	3.00	3.27	3.66	4.00	4.25	4.43	4.55	4.63	4.664
500	3.03	3.33	3.62	4.07	4.42	4.69	4.90	5.03	5.12	5.152

TABLE 534.—Coefficients in Formula for Proximity Factor of Equal Parallel Round Wires

The proximity factor of two equal parallel conductors may be calculated by the formula

$$P = 1 + [G.d^2/s^2]/[F(1 - Hd^2/s^2)]$$

in which the coefficient F is to be obtained from Table 532 for the given value of f/R_0 and the coefficients G and H are to be taken from the table below for the given value of f/R_0. In the table below the values of H apply to currents in the same direction; in the case of currents in opposite directions H' is to be used. In the above formula d is the diameter of the wires and s their axial spacing. The proximity factor for two equal parallel tubular conductors does not differ much from the value for two solid wires with the same axial spacing and a value of f/R_0 one-half the value for two solid wires of the same diameter, except for conductors very close together.

$\sqrt{f/R_0}$	G	H	H'	$\sqrt{f/R_0}$	G	H	H'
0	0	+0.0417	+0.0417	200	0.8491	−0.1904	0.5530
25	0.0036	.0395	.0443	250	1.0959	− .2017	.5932
50	.0519	+ .0109	.0798	300	1.340	− .2093	.6200
75	.1903	− .0659	.1838	350	1.585	− .2149	.6389
100	.3562	− .1379	.3112	400	1.830	− .2191	.6530
125	.4914	− .1685	.4114	450	2.073	− .2224	.6639
150	.6096	− .1776	.4787	500	2.319	− .2231	.6722
175	.7277	− .1839	.5228				

TABLE 535.– Ratio of Alternating to Direct Current Resistances for Copper Wires

This table gives the ratio of the resistance of straight copper wires with alternating currents of different frequencies to the value of the resistance with direct currents.

Diameter of wire in millimeters.	Frequency f =					
	60	100	1000	10,000	100,000	1,000,000
0.05	—	—	—	—	—	*1.001
0.1	—	—	—	—	*1.001	1.008
0.25	—	—	—	—	1.003	1.247
0.5	—	—	—	*1.001	1.047	2.240
1.0	—	—	—	1.008	1.503	4.19
2.0	—	—	1.001	1.120	2.756	8.10
3.	—	—	1.006	1.437	4.00	12.0
4.	—	—	1.021	1.842	5.24	17.4
5.	—	*1.001	1.047	2.240	6.49	19.7
7.5	1.001	1.002	1.210	3.22	7.50	29.7
10.	1.003	1.008	1.503	4.19	12.7	39.1
15.	1.016	1.038	2.136	6.14	18.8	—
20.	1.044	1.120	2.756	8.10	25.2	—
25.	1.105	1.247	3.38	10.1	28.3	—
40.	1.474	1.842	5.24	17.4	—	—
100.	3.31	4.19	13.7	39.1	—	—

Values between 1.000 and 1.001 are indicated by *1.001.

The values are for wires having an assumed conductivity of 1.60 microhm-cms; for copper wires at room temperatures the values are slightly less than as given in table.

The change of resistance of wire other than copper (iron wires excepted) may be calculated from the above table by taking it as proportional to $d\sqrt{f/\rho}$ where d = diameter, f the frequency and ρ the resistivity.

If a given wire be wound into a solenoid, its resistance, at a given frequency, will be greater than the values in the table, which apply to straight wires only. The resistance in this case is a complicated function of the pitch and radius of the winding, the frequency, and the diameter of the wire, and is found by experiment to be sometimes as much as twice the value for a straight wire.

TABLE 536.—Maximum Diameter of Wires for High-frequency Resistance Ratio of 1.01

Frequency ÷ 10^6. . .	0.1	0.2	0.4	0.6	0.8	1.0	1.2	1.5	2.0	3.0
Wave-length, meters	3000	1500	750	500	375	300	250	200	150	100
Material.	Diameter in centimeters.									
Copper	0.0356	0.0251	0.0177	0.0145	0.0125	0.0112	0.0102	0.0092	0.0079	0.0065
Silver	0.0345	0.0244	0.0172	0.0141	0.0122	0.0109	0.0099	0.0089	0.0077	0.0063
Gold	0.0420	0.0297	0.0210	0.0172	0.0149	0.0133	0.0121	0.0108	0.0094	0.0077
Platinum	0.1120	0.0793	0.0560	0.0457	0.0396	0.0354	0.0323	0.0290	0.0250	0.0205
Mercury	0.264	0.187	0.132	0.1080	0.0936	0.0836	0.0763	0.0683	0.0591	0.0483
Manganin	0.1784	0.1261	0.0892	0.0729	0.0631	0.0564	0.0515	0.0461	0.0399	0.0325
Constantan	0.1892	0.1337	0.0946	0.0772	0.0664	0.0598	0.0546	0.0488	0.0423	0.0345
German silver	0.1942	0.1372	0.0970	0.0792	0.0692	0.0614	0.0560	0.0500	0.0434	0.0354
Graphite	0.765	0.541	0.383	0.312	0.271	0.242	0.221	0.197	0.171	0.140
Carbon	1.60	1.13	0.801	0.654	0.566	0.506	0.462	0.414	0.358	0.292
Iron μ = 1000	0.00263	0.00186	0.00131	0.00108	0.00094	0.00083	0.00076	0.00068	0.00059	0.00048
μ = 500	0.00373	0.00264	0.00187	0.00152	0.00132	0.00118	0.00108	0.00096	0.00084	0.00068
μ = 100	0.00838	0.00590	0.00418	0.00340	0.00295	0.00264	0.00241	0.00215	0.00186	0.00152

Bureau of Standards Circular 74, Radio Instruments and Measurements, 1918.

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TABLE 537.—Radiation Resistances for Various Wave-Lengths and Antenna Heights

The radiation theory of Hertz shows that the radiated energy of an oscillator may be represented by $E = \text{constant}\ (h^2/\lambda^2)\ I^2$, where h is the length of the oscillator, λ, the wave-length and I the current at its center. For a flat-top antenna $E = 1600\ (h^2/\lambda^2)\ I^2$ watts; $1600\ h^2/\lambda^2$ is called the radiation resistance.

(h = height to center of capacity of conducting system.)

Wave-Length λ \ h =	40 Ft.	60 Ft.	80 Ft.	100 Ft.	120 Ft.	160 Ft.	200 Ft.	300 Ft.	450 Ft.	600 Ft.	1200 Ft.
m	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*
200	6.0	13.4	24.0	37.0	54.0	95.0					
300	2.7	6.0	10.6	16.5	23.8	42.4					
400	1.5	3.4	6.0	9.3	13.4	23.8					
600	0.66	1.5	2.7	4.1	6.0	10.6	16.4	37.4	84.0	149.0	
800	0.37	0.84	1.5	2.3	3.4	6.0	9.2	21.0	47.0	84.0	
1000	0.24	0.54	0.95	1.5	2.1	3.8	6.0	13.5	30.0	54.0	215.0
1200	0.17	0.37	0.66	1.03	1.5	2.6	4.1	9.3	21.0	37.0	149.0
1500	0.11	0.24	0.42	0.66	0.95	1.7	2.6	6.0	13.4	24.0	95.0
2000		0.13	0.24	0.37	0.54	0.95	1.5	3.4	7.5	13.4	54.0
2500			0.15	0.24	0.34	0.61	0.95	2.2	4.8	8.6	34.0
3000			0.11	0.17	0.24	0.42	0.66	1.5	3.4	6.0	24.0
4000			0.06	0.09	0.13	0.24	0.37	0.84	1.9	3.4	13.4
5000							0.24	0.53	1.20	2.2	8.6
6000							0.16	0.37	0.84	1.5	6.0
7000							0.12	0.27	0.61	1.1	4.4

Austin, Jour. Wash. Acad. of Sci. 1, p. 190, 1911.

TABLE 538.—The Dielectric Properties of Nonconductors

Phillips Thomas, J. Franklin Inst. 176, 283, 1913.

Results of tests at unit area and unit thickness of dielectric.				
At 1000 cycles.	Mica.	Paper.	Celluloid.	Ice.
Max. breakdown volts per cm.	1.06×10^6	0.71×10^6	1.05×10^6	$.011 \times 10^6$
Specific induc. capacity	4.00	4.90	13.26	86.40
Max. absorbable energy, watts-sec/cm³	0.198	0.108	0.640	.00040
90°-angle of lead	0° 57′	2° 10′	3° 40′	13° 39′
Equiv. resistance ohms/cm³ $\times 10^{11}$	3.91	9.84	48.3	1400
Conductivity per cm. cube $\times 10^{-10}$	2.56	1.02	0.207	.00722
Percent change in cap. per cycle $\times 10^4$	2.18	14.31	30.7	70.0
Percent change in resistance per cycle	0.258	0.146	0.106	0.127
At 15 cycles.				
Specific inductive capacity	4.09	5.77	18.60	429.0
Max. absorbable energy, watt-sec/cm³.	0.203	0.126	0.90	0.002
Percent change in capacity per cycle	0.00	0.306	1.74	1.59
On direct current.				
Conductivity per cm³	2.42×10^{-17}	2.27×10^{-14}	71.5×10^{-14}	$163. 10^{-11}$

Table 539
POWER FACTOR AND DIELECTRIC CONSTANT

(See also Table 540 on page 454.)

From the range of the values given, an approximate figure can be taken for a particular material and its relative position with respect to other materials seen. Data of this kind are much effected by the condition and past treatment of the samples, and by the conditions of the tests.

The power factor and dielectric constant of dry air may be taken as zero and 1.00. Fused quartz has the lowest power factor among the solid insulating materials, and is used for supporting the insulated plates of standard air condensers.

TABLE 539.—Values for Power Factor in Per Cent for Several Electrical Insulating Materials at Radio-Frequencies

Material	Frequency kc	Measurements reported by— 1	2	3	4	5
Amber	187.5	0.459	....	....	....	....
	300	.476	....	....	....	....
	600	.495	....	....	....	....
	1000	.513	....	....	....	....
Glass	30	....	....	....	0.35–2.98[b]	....
	600	0.040–0.653[a]	....	....	....	....
Cobalt glass	500	....	0.70	....	....	....
Flint glass	500	....	.42	....	....	....
	890	....	.40	....	....	....
Plate glass	14	....	....	0.97	....	....
	100	....	....	.77	....	0.93
	500	....	.70	.66	....	....
	635	....	....	....	....	.82
	1000	....	....	.62	....	....
Pyrex glass	14	....	....	.88	....	....
	30	....	....	....	0.56 and 0.26	....
	100	....	....	.74	....	.58
	420	....	....	....	....	.50
	500	....	.42	.67	....	....
	750	....	....	.68	....	....
Photographic glass	100	....	....	....	....	.95
	235	....	....	....	....	.86
	1700	....	....	....	....	.77
Hard rubber	135	....	....	....	....	.68
	315	....	....	....	....	.70
	600	.62	....	....	....	....
	625	....	....	....	....	.70
	710	....	.88	....	....	....
	1000	.68	....	....	....	....
	1085	....	....	....	....	.74
	1126	....	1.05	....	....	....
Marble[c]	80–650	....	....	....	....	0.35 –4.72
Mica	600	.017	....	....	....	.007– .93[f]
Laminated phenolic insulation[d]	190	....	3.85–7.35	....	....	2.62– 8.0
	1000	....	4.20–6.65	....	....	3.85– 5.6
Moulded phenolic insulation[d]	190	....	....	....	....	1.64–10.9
	1000	....	....	....	....	1.56– 8.4
Wood (oak)	300	....	3.68	....	....	13.8, 2.94[e]
	635	....	3.85	....	....	10.1, 3.24[e]
	1060	....	4.20	....	....	....
(maple)	500	....	3.33	....	....	3.63
(birch)	500	....	6.48	....	....	....
(baywood)	870	....	....	....	....	3.76
Paraffin	14	....	....	.042	....	....
	100	....	....	.031	....	.017
	500	....	....	.026	....	....
	1070	....	....	....	....	.034

(1) Schott, Erich, Hochfrequenzverluste von Gläsern und einigen anderen Dielektricis. Jahrb. Drahtlosen Tele. u. Tele., 18, 82–122, August, 1921. (2) Hoch, E. T. Power losses in insulating materials. Bell System Tech. Journ., 1, No. 2, Nov., 1922. (3) MacLeod, H. J. Power losses in dielectrics. Phys. Rev., 21, 53–73, 1923. (4) Decker, William C., Power losses in commercial glasses. Electr. World, 89, 601–603, March 19, 1927. (5) Data from the Bureau of Standards.

[a] Range of 27 samples. [b] Range of 9 samples. [c] Range of 10 samples. [d] Range of severalsamples. [e] After drying 48 hours at 80°C. [f] Range of a number of samples from different localities.

TABLE 540.—Values of Dielectric Constant for Several Electrical Insulating Materials at Radio-Frequencies

Material	Frequency, kc	Measurements reported by— 1	2	3	4
Glass	30	...	...	5.1–7.9[a]	...
Crown glass	230	6.3	...	...	...
	800	6.2	...	...	...
Flint glass	500	...	7.0	...	...
	890	...	7.0	...	...
Plate glass	500	...	6.8	...	7.6
Cobalt glass	500	...	7.3	...	...
Pyrex glass	30	...	...	4.8	...
	500	...	4.9	...	5.8
Photographic glass	100	...	...	...	7.5
	1700	...	...	...	7.4
Hard rubber	135	...	...	...	3.7
	210	...	3.0	...	...
	1126	...	3.0	...	3.7
Marble	44	8.4	...	...	...
	80–650	...	...	...	9.2–11.7[c]
	1400	7.3	...	...	...
Mica	100–1000	...	...	...	5.8–8.7
Laminated phenolic insulation	190	...	5.4–5.8	...	5.0–7.4
	1000	...	5.1–5.6	...	4.7–7.0
Moulded phenolic insulation	190	...	...	...	4.3–7.6
	1000	...	...	...	4.9–7.0
Wood (oak)	300	...	3.2	...	6.7, 3.1[b]
	425	...	3.3	...	...
	635	...	3.3	...	6.5, 3.0[b]
	1060	...	3.3	...	...
(maple)	500	...	4.4	...	4.4
(birch)	500	...	5.2	...	...
(baywood)	870	...	...	...	3.8

(1) Bairsto, G. E., Conductivity and dielectric constant of dielectrics for high-frequency oscillations. Proc. Roy. Soc. London, A, 96, 363–382, Jan., 1920. (2) Hoch, E. T., Power losses in insulating materials. Bell System Tech. Journ., 1, No. 2, Nov., 1922. (3) Decker, William C., Power losses in commercial glasses. Electr. World, 89, 601–603, March 19, 1927. (4) Data from the Bureau of Standards.

[a] Range of 9 samples of various chemical compositions reported. [b] After drying sample for 48 hours at 80°C. [c] Range of 10 samples of various kinds of marble.

TABLE 541.—Absorption Factors for Radio Propagation

For frequencies up to 1000 kc and transmission over sea water the semiempirical transmission formulas of Austin-Cohen, Austin, Fuller, and Espenschied, Anderson and Bailey take the form

$$F\ (\mu\ \text{volts/meter}) = (377/\lambda)(hI/d)\sqrt{\theta/\sin\theta}\cdot e^{\frac{-\alpha d}{\lambda^x}}$$

where the coefficient $377hI/\lambda d$ represents the simple Hertzian radiation field over a perfectly conducting plane surface, the factor $\sqrt{\theta/\sin\theta}$ corrects the formula for the curvature of the earth, and the factor $e^{-\alpha d/\lambda^x}$ is the absorption factor, α the damping factor, and x is determined experimentally. d, the distance from the transmitter, and λ, the wave length, both are measured in kilometers. The following tabulation completes the information concerning these formulas. (See next page.)

TABLE 541 (*continued*).—Absorption Factors for Radio Propagation

Name of formula	Damping factor	x	Nature of path	Distance km	Frequency kc	Remarks
Austin-Cohen	0.0015	0.5	Sea water	Up to 2000	80–1000	
Austin revised	.0014	.6	Sea water	Up to 12000	12–1000	
Fuller	.0045	1.4	Sea water	3900	25.4–100	(*a*)
E, A, and B	.005	1.25	Sea water	5000	17–60	(*b*)

(*a*) Honolulu to San Francisco. (*b*) Omitted factor $\sqrt{\theta/\sin\theta}$, E, A, and B, Espenschied, Anderson and Bailey.

Bown and Gillet substituting their measured values of F, at 640 kc taken within 150 km of Washington, D. C., in the Austin-Cohen formula get

α = 0.028 for dry sandy soil; 0.009 for moist soil; 0.0025 for ½ salt water (Chesapeake Bay).

Austin concludes that for frequencies greater than 60 kc over land, absorption is considerably greater than over sea water. From 60 kc to 20 kc overland absorption decreases and approaches that over sea water. In these results the total field received in the day time is considered. In the following results the ground wave only is considered.

Over land especially at the higher frequencies there are so many variables that no simple complete formula is available for F. We may write Fxd = a constant from the Hertzian formula and modify it by a factor A for absorption and quote some results, i.e.

$$F = (377hI/\lambda D)A$$

Smith, Rose, and Barfield calculated from Sommerfeld's theory and approximately checked at some broadcast frequencies the following results.

TABLE 542.—Transmission Path Over Sea Water Whose Conductivity Was Assumed = 1.1×10^{-11} e.m.u.

Frequency, kc		50 km	100 km	150 km
10000	Absorption factors	1	0.92	0.80
3000		1	1	1

TABLE 543.—Transmission Path Over Land Whose Conductivity Was Assumed = 1.1×10^{-13} e.m.u.

Frequency, kc	Absorption factor at a distance of—									
	1.5 km	4 km	5 km	10 km	15 km	25 km	50 km	75 km	100 km	150 km
300	....	....	....	....	....	....	0.98	....	0.93	0.82
1000	....	....	....	....	....	0.56	.29	0.20	.14	.08
3000	....	....	0.40	0.20	0.10	....	....	....	....	....
10000	0.10	0.03	....	....	....	....	....	....	....	....

Rolf calculates from Sommerfeld's theory the following:

TABLE 544.—Transmission Path Over Land Whose Inductivity ϵ = 15 e.s.u. and Whose Conductivity $\delta = 10^{-13}$ e.m.u. (Good Conducting Ground)

Frequency, kc	Absorption factor at a distance of—				
	2 km	5 km	10 km	40 km	100 km
300	....	....	....	....	0.90
1000	....	....	0.80	....	.25
3000	....	....	.30	0.04	....
10000	0.16	0.05	.02	....	....

TABLE 545.—Transmission Path Over Ground With Inductivity ϵ = 15 e.s.u. and Conductivity $\sigma = 10^{-15}$ e.m.u. (Bad Conducting Ground)

Frequency, kc	Absorption factor at a distance of—			
	10 km	20 km	50 km	100 km
75	....	....	....	0.90
150	....	....	....	.70
300	....	....	0.50	.10
500	0.90	0.40	.10	....
1000	.40	....	....	....

TABLE 546

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KILOCYCLE-METER CONVERSION TABLE

Velocity of propagation, 299820 km/sec.

The number of kilocycles (kc) is the number of thousands of times the rapidly alternating current in the antenna repeats its direction of flow per sec. The smaller the wave length, the larger the frequency. To obtain approximate kc divide 300000 by the number of m (see next table). For accurate conversion the constant is 299820. The wave length is equal to the velocity divided by the frequency. The velocity of radio waves in space, according to the best available data, is 299820 km/sec. This table and the next are entirely reversible, i.e., 50 kc is 5996 m, and also 50 m is 5996 kc. The range of the table is easily extended by shifting the decimal point in opposite directions for each pair of values—e.g., 2230 kc or m is equivalent to 134.4 m or kc; whence 223 kc or m is equivalent to 1344 m or kc. (Taken from Bur. Standards, Misc. Publ., 67, 1925.)

kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc
1,010	296.9	1,410	212.6	1,810	165.6	2,210	135.7	2,610	114.9
1,020	293.9	1,420	211.1	1,820	164.7	2,220	135.1	2,620	114.4
1,030	291.1	1,430	209.7	1,830	163.8	2,230	134.4	2,630	114.0
1,040	288.3	1,440	208.2	1,840	162.9	2,240	133.8	2,640	113.6
1,050	285.5	1,450	206.8	1,850	162.1	2,250	133.3	2,650	113.1
1,060	282.8	1,460	205.4	1,860	161.2	2,260	132.7	2,660	112.7
1,070	280.2	1,470	204.0	1,870	160.3	2,270	132.1	2,670	112.3
1,080	277.6	1,480	202.6	1,880	159.5	2,280	131.5	2,680	111.9
1,090	275.1	1,490	201.2	1,890	158.6	2,290	130.9	2,690	111.5
1,100	272.6	1,500	199.9	1,900	157.8	2,300	130.4	2,700	111.0
1,110	270.1	1,510	198.6	1,910	157.0	2,310	129.8	2,710	110.6
1,120	267.7	1,520	197.2	1,920	156.2	2,320	129.2	2,720	110.2
1,130	265.3	1,530	196.0	1,930	155.3	2,330	128.7	2,730	109.8
1,140	263.0	1,540	194.7	1,940	154.5	2,340	128.1	2,740	109.4
1,150	260.7	1,550	193.4	1,950	153.8	2,350	127.6	2,750	109.0
1,160	258.5	1,560	192.2	1,960	153.0	2,360	127.0	2,760	108.6
1,170	256.3	1,570	191.0	1,970	152.2	2,370	126.5	2,770	108.2
1,180	254.1	1,580	189.8	1,980	151.4	2,380	126.0	2,780	107.8
1,190	252.0	1,590	188.6	1,990	150.7	2,390	125.4	2,790	107.5
1,200	249.9	1,600	187.4	2,000	149.9	2,400	124.9	2,800	107.1
1,210	247.8	1,610	186.2	2,010	149.2	2,410	124.4	2,810	106.7
1,220	245.8	1,620	185.1	2,020	148.4	2,420	123.9	2,820	106.3
1,230	243.8	1,630	183.9	2,030	147.7	2,430	123.4	2,830	105.9
1,240	241.8	1,640	182.8	2,040	147.0	2,440	122.9	2,840	105.6
1,250	239.9	1,650	181.7	2,050	146.3	2,450	122.4	2,850	105.2
1,260	238.0	1,660	180.6	2,060	145.5	2,460	121.9	2,860	104.8
1,270	236.1	1,670	179.5	2,070	144.8	2,470	121.4	2,870	104.5
1,280	234.2	1,680	178.5	2,080	144.1	2,480	120.9	2,880	104.1
1,290	232.4	1,690	177.4	2,090	143.5	2,490	120.4	2,890	103.7
1,300	230.6	1,700	176.4	2,100	142.8	2,500	119.9	2,900	103.4
1,310	228.9	1,710	175.3	2,110	142.1	2,510	119.5	2,910	103.0
1,320	227.1	1,720	174.3	2,120	141.4	2,520	119.0	2,920	102.7
1,330	225.4	1,730	173.3	2,130	140.8	2,530	118.5	2,930	102.3
1,340	223.7	1,740	172.3	2,140	140.1	2,540	118.0	2,940	102.0
1,350	222.1	1,750	171.3	2,150	139.5	2,550	117.6	2,950	101.6
1,360	220.4	1,760	170.4	2,160	138.8	2,560	117.1	2,960	101.3
1,370	218.8	1,770	169.4	2,170	138.1	2,570	116.7	2,970	100.9
1,380	217.3	1,780	168.4	2,180	137.5	2,580	116.2	2,980	100.6
1,390	215.7	1,790	167.5	2,190	136.9	2,590	115.8	2,990	100.3
1,400	214.2	1,800	166.6	2,200	136.3	2,600	115.3	3,000	99.94

WIRELESS TELEGRAPHY

KILOCYCLE-METER CONVERSION TABLE

Velocity of propagation, 299820 km/sec.

kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc
3,010	99.61	3,510	85.42	4,010	74.77	4,510	66.48	5,010	59.84
3,020	99.28	3,520	85.18	4,020	74.58	4,520	66.33	5,020	59.73
3,030	98.95	3,530	84.94	4,030	74.40	4,530	66.19	5,030	59.61
3,040	98.62	3,540	84.70	4,040	74.21	4,540	66.04	5,040	59.49
3,050	98.30	3,550	84.46	4,050	74.03	4,550	65.89	5,050	59.37
3,060	97.98	3,560	84.22	4,060	73.85	4,560	65.75	5,060	59.25
3,070	97.66	3,570	83.98	4,070	73.67	4,570	65.61	5,070	59.13
3,080	97.34	3,580	83.75	4,080	73.49	4,580	65.46	5,080	59.02
3,090	97.03	3,590	83.52	4,090	73.31	4,590	65.32	5,090	58.90
3,100	96.72	3,600	83.28	4,100	73.13	4,600	65.18	5,100	58.79
3,010	96.41	3,610	83.05	4,110	72.95	4,610	65.04	5,110	58.67
3,120	96.10	3,620	82.82	4,120	72.77	4,620	64.90	5,120	58.56
3,130	95.79	3,630	82.60	4,130	72.60	4,630	64.76	5,130	58.44
3,140	95.48	3,640	82.37	4,140	72.42	4,640	64.62	5,140	58.33
3,150	95.18	3,650	82.14	4,150	72.25	4,650	64.48	5,150	58.22
3,160	94.88	3,660	81.92	4,160	72.07	4,660	64.34	5,160	58.10
3,170	94.58	3,670	81.70	4,170	71.90	4,670	64.20	5,170	57.99
3,180	94.28	3,680	81.47	4,180	71.73	4,680	64.06	5,180	57.88
3,190	93.99	3,690	81.25	4,190	71.56	4,690	63.93	5,190	57.77
3,200	93.69	3,700	81.03	4,200	71.39	4,700	63.79	5,200	57.66
3,210	93.40	3,710	80.81	4,210	71.22	4,710	63.66	5,210	57.55
3,220	93.11	3,720	80.60	4,220	71.05	4,720	63.52	5,220	57.44
3,230	92.82	3,730	80.38	4,230	70.88	4,730	63.39	5,230	57.33
3,240	92.54	3,740	80.17	4,240	70.71	4,740	63.25	5,240	57.22
3,250	92.25	3,750	79.95	4,250	70.55	4,750	63.12	5,250	57.11
3,260	91.97	3,760	79.74	4,260	70.38	4,760	62.99	5,260	57.00
3,270	91.69	3,770	79.53	4,270	70.22	4,770	62.86	5,270	56.89
3,280	91.41	3,780	79.32	4,280	70.05	4,780	62.72	5,280	56.78
3,290	91.13	3,790	79.11	4,290	69.89	4,790	62.59	5,290	56.68
3,300	90.86	3,800	78.90	4,300	69.73	4,800	62.46	5,300	56.57
3,310	90.58	3,810	78.69	4,310	69.56	4,810	62.33	5,310	56.46
3,320	90.31	3,820	78.49	4,320	69.40	4,820	62.20	5,320	56.36
3,330	90.04	3,830	78.28	4,330	69.24	4,830	62.07	5,330	56.25
3,340	89.77	3,840	78.08	4,340	69.08	4,840	61.95	5,340	56.15
3,350	89.50	3,850	77.88	4,350	68.92	4,850	61.82	5,350	56.04
3,360	89.23	3,860	77.67	4,360	68.77	4,860	61.69	5,360	55.94
3,370	88.97	3,870	77.47	4,370	68.61	4,870	61.56	5,370	55.83
3,380	88.70	3,880	77.27	4,380	68.45	4,880	61.44	5,380	55.73
3,390	88.44	3,890	77.07	4,390	68.30	4,890	61.31	5,390	55.63
3,400	88.18	3,900	76.88	4,400	68.14	4,900	61.19	5,400	55.52
3,410	87.92	3,910	76.68	4,410	67.99	4,910	61.06	5,410	55.42
3,420	87.67	3,920	76.48	4,420	67.83	4,920	60.94	5,420	55.32
3,430	87.41	3,930	76.29	4,430	67.68	4,930	60.82	5,430	55.22
3,440	87.16	3,940	76.10	4,440	67.53	4,940	60.69	5,440	55.11
3,450	86.90	3,950	75.90	4,450	67.38	4,950	60.57	5,450	55.01
3,460	86.65	3,960	75.71	4,460	67.22	4,960	60.45	5,460	54.91
3,470	86.40	3,970	75.52	4,470	67.07	4,970	60.33	5,470	54.81
3,480	86.16	3,980	75.33	4,480	66.92	4,980	60.20	5,480	54.71
3,490	85.91	3,990	75.14	4,490	66.78	4,990	60.08	5,490	54.61
3,500	85.66	4,000	74.96	4,500	66.63	5,000	59.96	5,500	54.51

Table 546 (*continued*)

WIRELESS TELEGRAPHY

KILOCYCLE-METER CONVERSION TABLE

Velocity of propagation, 299820 km/sec.

kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc
5,510	54.41	6,010	49.89	6,510	46.06	7,010	42.77	7,510	39.92
5,520	54.32	6,020	49.80	6,520	45.98	7,020	42.71	7,520	39.87
5,530	54.22	6,030	49.72	6,530	45.91	7,030	42.65	7,530	39.82
5,540	54.12	6,040	49.64	6,540	45.84	7,040	42.59	7,540	39.76
5,550	54.02	6,050	49.56	6,550	45.77	7,050	42.53	7,550	39.71
5,560	53.92	6,060	49.48	6,560	45.70	7,060	42.47	7,560	39.66
5,570	53.83	6,070	49.39	6,570	45.63	7,070	42.41	7,570	39.61
5,580	53.73	6,080	49.31	6,580	45.57	7,080	42.35	7,580	39.55
5,590	53.64	6,090	49.23	6,590	45.50	7,090	42.29	7,590	39.50
5,600	53.54	6,100	49.15	6,600	45.43	7,100	42.23	7,600	39.45
5,610	53.44	6,110	49.07	6,610	45.36	7,110	42.17	7,610	39.40
5,620	53.35	6,120	48.99	6,620	45.29	7,120	42.11	7,620	39.35
5,630	53.25	6,130	48.91	6,630	45.22	7,130	42.05	7,630	39.29
5,640	53.16	6,140	48.83	6,640	45.15	7,140	41.99	7,640	39.24
5,650	53.07	6,150	48.75	6,650	45.09	7,150	41.93	7,650	39.19
5,660	52.97	6,160	48.67	6,660	45.02	7,160	41.87	7,660	39.14
5,670	52.88	6,170	48.59	6,670	44.95	7,170	41.82	7,670	39.09
5,680	52.79	6,180	48.51	6,680	44.88	7,180	41.76	7,680	39.04
5,690	52.69	6,190	48.44	6,690	44.82	7,190	41.70	7,690	38.99
5,700	52.60	6,200	48.36	6,700	44.75	7,200	41.64	7,700	38.94
5,710	52.51	6,210	48.28	6,710	44.68	7,210	41.58	7,710	38.89
5,720	52.42	6,220	48.20	6,720	44.62	7,220	41.53	7,720	38.84
5,730	52.32	6,230	48.13	6,730	44.55	7,230	41.47	7,730	38.79
5,740	52.23	6,240	48.05	6,740	44.48	7,240	41.41	7,740	38.74
5,750	52.14	6,250	47.97	6,750	44.42	7,250	41.35	7,750	38.69
5,760	52.05	6,260	47.89	6,760	44.35	7,260	41.30	7,760	38.64
5,770	51.96	6,270	47.82	6,770	44.29	7,270	41.24	7,770	38.59
5,780	51.87	6,280	47.74	6,780	44.22	7,280	41.18	7,780	38.54
5,790	51.78	6,290	47.67	6,790	44.16	7,290	41.13	7,790	38.49
5,800	51.69	6,300	47.59	6,800	44.09	7,300	41.07	7,800	38.44
5,810	51.60	6,310	47.52	6,810	44.03	7,310	41.02	7,810	38.39
5,820	51.52	6,320	47.44	6,820	43.96	7,320	40.96	7,820	38.34
5,830	51.43	6,330	47.36	6,830	43.90	7,330	40.90	7,830	38,29
5,840	51.34	6,340	47.29	6,840	43.83	7,340	40.85	7,840	38.24
5,850	51.25	6,350	47.22	6,850	43.77	7,350	40.79	7,850	38.19
5,860	51.16	6,360	47.14	6,860	43.71	7,360	40.74	7,860	38.14
5.870	51.08	6,370	47.07	6,870	43.64	7,370	40.68	7,870	38.10
5,880	50.99	6,380	46.99	6,880	43.58	7,380	40.63	7,880	38.05
5,890	50.90	6,390	46.92	6,890	43.52	7,390	40.57	7.890	38.00
5,900	50.82	6,400	46.85	6,900	43.45	7,400	40.52	7,900	37.95
5,910	50.73	6,410	46.77	6,910	43.39	7,410	40.46	7.910	37.90
5,920	50.65	6,420	46.70	6,920	43.33	7,420	40.41	7,920	37.86
5,930	50.56	6,430	46.63	6,930	43.26	7,430	40.35	7,930	37.81
5,940	50.47	6,440	46.56	6,940	43.20	7,440	40.30	7,940	37.76
5,950	50.39	6,450	46.48	6,950	43.14	7,450	40.24	7,950	37.71
5,960	50.31	6,460	46.41	6,960	43.08	7,460	40.19	7,960	37.67
5,970	50.22	6,470	46.34	6,970	43.02	7,470	40.14	7,970	37.62
5,980	50.14	6,480	46.27	6,980	42.95	7,480	40.08	7,980	37.57
5,990	50.05	6,490	46.20	6,990	42.89	7,490	40.03	7,990	37.52
6,000	49.97	6,500	46.13	7,000	42.83	7,500	39.98	8,000	37.48

TABLE 546 (*concluded*)

WIRELESS TELEGRAPHY

KILOCYCLE-METER CONVERSION TABLE

Velocity of propagation, 299820 km/sec.

kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc	kc or m	m or kc
8,010	37.43	8,410	35.65	8,810	34.03	9,210	32.55	9,610	31.20
8,020	37.38	8,420	35.61	8,820	33.99	9,220	32.52	9,620	31.17
8,030	37.34	8,430	35.57	8,830	33.95	9,230	32.48	9,630	31.13
8,040	37.29	8,440	35.52	8,840	33.92	9,240	32.45	9,640	31.10
8,050	37.24	8,450	35.48	8,850	33.88	9,250	32.41	9,650	31.07
8,060	37.20	8,460	35.44	8,860	33.84	9,260	32.38	9,660	31.04
8,070	37.15	8,470	35.40	8,870	33.80	9,270	32.34	9,670	31.01
8,080	37.11	8,480	35.36	8,880	33.76	9,280	32.31	9,680	30.97
8,090	37.06	8,490	35.31	8,890	33.73	9,290	32.27	9,690	30.94
8,100	37.01	8,500	35.27	8,900	33.69	9,300	32.24	9,700	30.91
8,110	36.97	8,510	35.23	8,910	33.65	9,310	32.20	9,710	30.88
8,120	36.92	8,520	35.19	8,920	33.61	9,320	32.17	9,720	30.85
8,130	36.88	8,530	35.15	8,930	33.57	9,330	32.14	9,730	30.81
8,140	36.83	8,540	35.11	8,940	33.54	9,340	32.10	9,740	30.78
8,150	36.79	8,550	35.07	8,950	33.50	9,350	32.07	9,750	30.75
8,160	36.74	8,560	35.03	8,960	33.46	9,360	32.03	9,760	30.72
8,170	36.70	8,570	34.98	8,970	33.42	9,370	32.00	9,770	30.69
8,180	36.65	8,580	34.94	8,980	33.39	9,380	31.96	9,780	30.66
8,190	36.61	8,590	34.90	8,990	33.35	9,390	31.93	9,790	30.63
8,200	36.56	8,600	34.86	9,000	33.31	9,400	31.90	9,800	30.59
8,210	36.52	8,610	34.82	9,010	33.28	9,410	31.86	9,810	30.56
8,220	36.47	8,620	34.78	9,020	33.24	9,420	31.83	9,820	30.53
8,230	36.43	8,630	34.74	9,030	33.20	9,430	31.79	9,830	30.50
8,240	36.39	8,640	34.70	9,040	33.17	9,440	31.76	9,840	30.47
8,250	36.34	8,650	34.66	9,050	33.13	9,450	31.73	9,850	30.44
8,260	36.30	8,660	34.62	9,060	33.09	9,460	31.69	9,860	30.41
8,270	36.25	8,670	34.58	9,070	33.06	9,470	31.66	9,870	30.38
8,280	36.21	8,680	34.54	9,080	33.02	9,480	31.63	9,880	30.35
8,290	36.17	8,690	34.50	9,090	32.98	9,490	31.59	9,890	30.32
8,300	36.12	8,700	34.46	9,100	32.95	9,500	31.56	9,900	30.28
8,310	36.08	8,710	34.42	9,110	32.91	9,510	31.53	9,910	30.25
8,320	36.04	8,720	34.38	9,120	32.88	9,520	31.49	9,920	30.22
8,330	35.99	8,730	34.34	9,130	32.84	9,530	31.46	9,930	30.19
8,340	35.95	8,740	34.30	9,140	32.80	9,540	31.43	9,940	30.16
8,350	35.91	8,750	34.27	9,150	32.77	9,550	31.39	9,950	30.13
8,360	35.86	8,760	34.23	9,160	32.73	9,560	31.36	9,960	30.10
8,370	35.82	8,770	34.19	9,170	32.70	9,570	31.33	9,970	30.07
8,380	35.78	8,780	34.15	9,180	32.66	9,580	31.30	9,980	30.04
8,390	35.74	8,790	34.11	9,190	32.62	9,590	31.26	9,990	30.01
8,400	35.69	8,800	34.07	9,200	32.59	9,600	31.23	10,000	29.98

Table 547

WIRELESS TELEGRAPHY

Wave-Length in Meters, Frequency in periods per second, and Oscillation Constant LC in Microhenries and Microfarads

The relation between the free wave-length in meters, the frequency in cycles per second, and the capacity-inductance product in microfarads and microhenries are given for circuits between 1000 and 10,000 meters. For values between 100 and 1000 meters, multiply the columns for n by 10 and move the decimal point of the corresponding LC column two places to the left (dividing by 100); for values between 10,000 and 100,000, divide the n column by 10 and multiply the LC column by 100. The relation between wave-length and capacity-inductance may be relied upon throughout the table to within one part in 200.

Example 1: What is the natural wave-length of a circuit containing a capacity of 0.001 microfarad, and an inductance of 454 microhenries? The product of the inductance and capacity is $454 \times 0.001 = 0.454$. Find 0.454 under LC; opposite under meters is 1270 meters, the natural wave-length of the circuit.

Example 2: What capacity must be associated with an inductance of 880 microhenries in order to tune the circuit to 3500 meters? Find opposite 3500 meters the LC value 3.45; divide this by 880, and the quotient, 0.00397, is the desired capacity in microfarads.

Example 3: A condenser has the capacity of 0.004 microfarad. What inductance must be placed in series with this condenser in order that the circuit shall have a wave-length of 600 meters? From the table, the LC value corresponding to 600 meters is 0.101. Divide this by 0.004, the capacity of the condenser, and the desired inductance is 25.2 microhenries.

Meters.	n	LC	Meters.	n	LC	Meters.	n	LC
1000	300,000	0.281	1300	230,800	0.476	1600	187,500	0.721
1010	297,000	0.287	1310	229,000	0.483	1610	186,300	0.730
1020	294,100	0.293	1320	227,300	0.490	1620	185,200	0.739
1030	291,300	0.299	1330	225,600	0.498	1630	184,100	0.748
1040	288,400	0.305	1340	223,900	0.505	1640	182,900	0.757
1050	285,700	0.310	1350	222,200	0.513	1650	181,800	0.766
1060	283,600	0.316	1360	220,600	0.521	1660	180,700	0.776
1070	280,400	0.322	1370	218,900	0.529	1670	179,600	0.785
1080	277,800	0.328	1380	217,400	0.536	1680	178,600	0.794
1090	275,200	0.335	1390	215,800	0.544	1690	177,500	0.804
1100	272,700	0.341	1400	214,300	0.552	1700	176,500	0.813
1110	270,300	0.347	1410	212,800	0.559	1710	175,400	0.823
1120	267,900	0.353	1420	211,300	0.567	1720	174,400	0.833
1130	265,500	0.359	1430	209,800	0.576	1730	173,400	0.842
1140	263,100	0.366	1440	208,300	0.584	1740	172,400	0.852
1150	260,900	0.372	1450	206,900	0.592	1750	171,400	0.862
1160	258,600	0.379	1460	205,500	0.600	1760	170,500	0.872
1170	256,400	0.385	1470	204,100	0.608	1770	169,400	0.882
1180	254,200	0.392	1480	202,700	0.617	1780	168,500	0.892
1190	252,100	0.399	1490	201,300	0.625	1790	167,600	0.902
1200	250,000	0.405	1500	200,000	0.633	1800	166,700	0.912
1210	247,900	0.412	1510	198,700	0.642	1810	165,700	0.923
1220	245,900	0.419	1520	197,400	0.650	1820	164,800	0.933
1230	243,900	0.426	1530	196,100	0.659	1830	163,900	0.943
1240	241,900	0.433	1540	194,800	0.668	1840	163,000	0.953
1250	240,000	0.440	1550	193,600	0.676	1850	162,200	0.963
1260	238,100	0.447	1560	192,300	0.685	1860	161,300	0.974
1270	236,200	0.454	1570	191,100	0.694	1870	160,400	0.985
1280	234,400	0.461	1580	189,900	0.703	1880	159,600	0.995
1290	232,600	0.468	1590	188,700	0.712	1890	158,700	1.006

Adapted from table prepared by Greenleaf W. Picard; copyright by Wireless Specialty Apparatus Company, New York. Computed on basis of 300,000 kilometers per second for the velocity of propagation of electromagnetic waves.

TABLE 547 (continued)

WIRELESS TELEGRAPHY

Wave-Length, Frequency and Oscillation Constant

Meters.	n	LC	Meters.	n	LC	Meters.	n	LC
1900	157,900	1.016	2800	107,100	2.21	7000	42,860	13.8
1910	157,100	1.026	2820	106,400	2.24	7100	42,250	14.2
1920	156,300	1.037	2840	105,600	2.27	7200	41,670	14.6
1930	155,400	1.048	2860	104,900	2.30	7300	41,100	15.0
1940	154,600	1.059	2880	104,200	2.33	7400	40,540	15.4
1950	153,800	1.070	2900	103,400	2.37	7500	40,000	15.8
1960	153,100	1.081	2920	102,700	2.40	7600	39,470	16.3
1970	152,300	1.092	2940	102,000	2.43	7700	38,960	16.7
1980	151,500	1.103	2960	101,300	2.47	7800	38,460	17.1
1990	150,800	1.114	2980	100,700	2.50	7900	37,980	17.6
2000	150,000	1.126	3000	100,000	2.53	8000	37,500	18.0
2020	148,500	1.148	3100	96,770	2.70	8100	37,040	18.5
2040	147,100	1.171	3200	93,750	2.88	8200	36,590	18.9
2060	145,600	1.194	3300	90,910	3.07	8300	36,140	19.4
2080	144,200	1.218	3400	88,240	3.26	8400	35,710	19.9
2100	142,900	1.241	3500	85,910	3.45	8500	35,290	20.3
2120	141,500	1.265	3600	83,330	3.65	8600	34,880	20.8
2140	140,200	1.289	3700	81,080	3.85	8700	34,480	21.3
2160	138,900	1.313	3800	78,950	4.06	8800	34,090	21.8
2180	137,600	1.338	3900	76,920	4.28	8900	33,710	22.3
2200	136,400	1.362	4000	75,000	4.50	9000	33,330	22.8
2220	135,100	1.387	4100	73,170	4.73	9100	32,970	23.3
2240	133,900	1.412	4200	71,430	4.96	9200	32,610	23.8
2260	132,700	1.438	4300	69,770	5.20	9300	32,260	24.3
2280	131,600	1.463	4400	68,180	5.45	9400	31,910	24.9
2300	130,400	1.489	4500	66,670	5.70	9500	31,590	25.4
2320	129,300	1.515	4600	65,220	5.96	9600	31,250	25.9
2340	128,200	1.541	4700	63,830	6.22	9700	30,930	26.5
2360	127,100	1.568	4800	62,500	6.49	9800	30,610	27.0
2380	126,000	1.594	4900	61,220	6.76	9900	30,310	27.6
2400	125,000	1.621	5000	60,000	7.04	10000	30,000	28.1
2420	124,000	1.648	5100	58,820	7.32			
2440	129,000	1.676	5200	57,690	7.61			
2460	121,900	1.703	5300	56,600	7.91			
2480	121,000	1.731	5400	55,560	8.21			
2500	120,000	1.759	5500	54,550	8.51			
2520	119,000	1.787	5600	53,570	8.83			
2540	118,100	1.816	5700	52,630	9.15			
2560	117,200	1.845	5600	51,720	9.47			
2580	116,300	1.874	5900	50,850	9.81			
2600	115,400	1.903	6000	50,000	10.1			
2620	114,500	1.932	6100	49,180	10.5			
2640	113,600	1.962	6200	48,550	10.8			
2660	112,800	1.991	6300	47,620	11.1			
2680	111,900	2.02	6400	46,870	11.5			
2700	111,100	2.05	6500	46,150	11.9			
2720	110,300	2.08	6600	45,450	12.3			
2740	109,500	2.11	6700	44,780	12.6			
2760	108,700	2.14	6800	44,120	13.0			
2780	107,900	2.18	6900	43,480	13.4			
2800	107,100	2.21	7000	42,860	13.8			

Table 548

SKIP-DISTANCE AND RANGE TABLE

For frequencies between 1500 and 30000 kc

(This table was prepared by the Naval Research Laboratory.)

Frequency in kilocycles	Range of ground wave	Skip-distance				Maximum reliable range				
		Summer		Winter		Summer		Winter		
		Day	Night	Day	Night	Day	Night	Day	Night	Note
1500– 1715	100	....	....	....	....	100	100	150	300	b, g
1715– 2000	90	....	....	....	....	120	175	170	600	b, c, h, d
2000– 2250	85	....	....	....	....	130	250	200	750	b, c, i
2250– 2750	80	....	....	....	....	150	350	220	1500	b, j
2750– 2850	70	....	....	....	....	170	500	300	2500	c, k
2850– 3500	65	....	....	....	....	200	900	350	3000	b, c, l
3500– 4000	60	....	....	....	....	250	1500	400	4500	b, c, d, h
4000– 5500	55	....	....	....	....	300	4000	500	7000	b, c, m
5500– 5700	50	....	....	....	....	400	4000	600	8000	b
5700– 6000	50	50	50	50	60	450	5000	650	8000	c
6000– 6150	50	60	70	60	90	500	5500	700	8000	e
6150– 6675	45	70	115	80	175	550	6500	750	8000	b
6675– 7000	45	80	185	100	290	650	7000	820	8000	c
7000– 7300	45	90	220	115	360	700	7500	900	8000	d
7300– 8200	40	140	290	175	465	750	8000	1100	8000	c
8200– 8550	40	160	370	200	570	800	8000	1300	8000	b
8550– 8900	40	170	420	230	630	900	8000	1460	8000	b, c
8900– 9500	40	200	485	270	710	950	8000	1680	8000	c
9500– 9600	40	220	530	280	740	1000	8000	1820	8000	e
9600–11000	35	260	625	325	860	1100	8000	2140	8000	c
11000–11400	35	300	750	380	1000	1200	8000	2460	8000	b
11400–11700	35	315	800	400	1080	1300	8000	2700		e
11700–11900	35	335	835	420	1120	1500	8000	2800		c
11900–12300	30	350	870	430	1170	1550	8000	3000		c
12300–12825	30	370	940	460	1240	1600	8000	3200		b
12825–13350	30	390	1000	485		1700	8000	3440		b, c
13350–14000	30	420	1075	510		1800		3660		c
14000–14400	30	440	1150	545		1950		4060		d
14400–15100	30	460	1230	580		2200		4360		c
15100–15350	30	475	1300	610		2300		4640		e
15350–16400	30	500	1370	640		2500		5060		c
16400–17100	25	550		700		3000		5600	Not useful	b
17100–17750	25	580		740		3500		6200		b, c
17750–17800	25	600		755	Not reflected	4000	Not useful	6450		e
17800–21450	20	660		835		5000		7000		c
21450–21550	20	750		1050		6000		7000		e
21550–22300	20	780	Not reflected	1090		7000		7000		b
22300–23000	20	835		1130		7000		7000		b, c
23000–28000	15	900		1200		un-known		un-known		f
28000–30000	10	1000		1400		un-known		un-known		d

Skip-distance—Shortest distance beyond the ground wave at which communication is possible, or the point where the sky wave first comes to earth. On certain frequences and at certain seasons communication is possible within the skip-distance due to echoes and around the world signals. Skip-distance variations are not so very large in the day time but they may be quite variable at night. It should be noted that the ground wave variations ranges are based upon overland data; the ranges over sea are considerably greater. Useful working ranges are, however, based entirely upon the sky wave.

The above table was obtained from the general average of a large number of observations. For the night ranges given it is assumed that the greater part of the path between the transmitting and receiving stations is in darkness.

As the distances given in this table are general averages many discrepancies may be found in practice due to seasonal changes, sun spot activities, geographical location, local weather conditions, etc.

(a) For approximate wave lengths use Table 547. (b) Mobile, ships and coastal stations, aircraft, railroad stock, etc. (c) Fixed, permanent stations handling point to point traffic. (d) Amateur. (e) Broadcast. (f) Not reserved. (g) 1601 experimental, 1600–1652–1664–1680–1704–1712, portable. (h) U. S. entirely amateur. (i) U. S. 2002–2300 experimental visual broadcasting. (j) 2398 experimental. (k) 2750–2950 experimental visual broadcasting. (l) 3088 experimental. (m) 4795 experimental.

MAGNETIC PROPERTIES

DEFINITIONS AND GENERAL DISCUSSION

Unit pole is a quantity of magnetism repelling another unit pole with a force of one dyne; 4π lines of force radiate from it. M, pole strength; $4\pi M$ lines of force radiate from pole of strength M.

H, field strength, = no. of lines of force crossing unit area in normal direction; unit = gauss = one line per unit area.

M, magnetic moment, = Ml, where l is length between poles of magnet.

I, intensity of magnetization or pole strength per unit area, = $\mathbf{M}/V = M/A$ where A is cross section of uniformly magnetized pole face, and V is the volume of the magnet. $4\pi M/A = 4\pi I$ = no. lines of force leaving unit area of pole.

J, specific intensity of magnetism, = I/ρ where ρ = density, g/cm³.

ϕ, magnetic flux, = $4\pi M + HA$ for magnet placed in field of strength H (axis parallel to field). Unit, the maxwell.

B, flux density (magnetic) induction, = $\phi/A = 4\pi I + H$; unit the gauss, maxwell per cm.

μ, magnetic permeability, = B/H. Strength of field in air-filled solenoid = $H = (4\pi/10)\, ni$ in gausses, i in amperes, n, number of turns per cm length. If iron filled, induction increased, i.e., no. of lines of force per unit area, B, passing through coil is greater than H; $\mu = B/H$.

κ, susceptibility; permeability relates to effect of iron core on magnetic field strength of coil; if effect be considered on iron core, which becomes a magnet of pole strength M and intensity of magnetism I, then the ratio $I/H = (\mu - 1)/4\pi$ is the magnetic susceptibility per unit volume and is a measure of the magnetizing effect of a magnetic field on the material placed in the field. $\mu = 4\pi\kappa + 1$.

χ, specific susceptibility (per unit mass) = $\kappa/\rho = J/H$.

χ_A, atomic susceptibility, = $\chi \times$ (atomic weight); χ_M = molecular susceptibility.

J_A, J_M, similarly atomic and molecular intensity of magnetization.

Hysteresis is work done in taking a cm³ of the magnetic material through a magnetic cycle = $\int H\, dI = (1/4\pi)\int H\, dB$. Steinmetz's empirical formula gives a close approximation to the hysteresis loss; it is $aB^{1.6}$ where B is the max. induction and a is a constant (see Table 575). The retentivity (B_r) is the value of B when the magnetizing force is reduced to zero. The reversed field necessary to reduce the magnetism to zero is called the coercive force (H_c).

Ferromagnetic substances, μ very large, κ very large: Fe, Ni, Co, Heusler's alloy (Cu 62.5, Mn 23.5, Al 14. See Stephenson, Phys. Rev. 1910), magnetite and a few alloys of Mn. μ for Heusler's alloy, 90 to 100 for B = 2200; for Si sheet steel 350 to 5300.

Paramagnetic substances, $\mu > 1$, very small but positive, $\kappa = 10^{-3}$ to 10^{-6}: oxygen, especially at low temperatures, salts of Fe, Ni, Mn, many metallic elements. (See Table 580.)

Diamagnetic substances, $\mu < 1$, κ negative. Most diamagnetic substance known is Bi, -14×10^{-6}. Volume susceptibility (see Table 580).

Paramagnetic substances show no retentivity or hysteresis effect. Susceptibility independent of field strength. The specific susceptibility for both para- and diamagnetic substances is independent of field strength.

For Hall effect (galvanomagnetic difference of potential), Ettinghausen effect (galvanomagnetic difference of temperature), Nernst effect (thermomagnetic difference of potential) and the Leduc effect (thermomagnetic difference of temperature), see Tables 593 and 594.

Magneto-strictive phenomena:

Joule effect: Mechanical change in length when specimen is subjected to a magnetic field. With increasing field strength, iron and some iron alloys show first a small increment $\Delta l/l$ = $(7 \text{ to } 35) \times 10^{-7}$, then a decrement, and for H = 1600, $\Delta l/l$ may amount to $-(6 \text{ to } 8) \times 10^{-6}$. Cast cobalt with increasing field first decreases, $\Delta l/l = -8 \times 10^{-6}$, H = 150, then increases in length, $\Delta l/l = +5 \times 10^{-6}$, H = 2000; annealed cobalt steadily contracts, $\Delta l/l = -25 \times 10^{-6}$, H = 2000. Ni rapidly then slowly contracts, $\Delta l/l = -30 \times 10^{-6}$, H = 100; -35×10^{-6}, H = 300; -36×10^{-6}, H = 2000 (Williams, Phys. Rev. 34, 44, 1912). A transverse field generally gives a reciprocal effect.

Wiedemann effect: The lower end of a vertical wire, magnetized longitudinally, when a current is passed through it, if free, twists in a certain direction, depending upon circumstances (see Williams, Phys. Rev. 32, 281, 1911). A reciprocal effect is observed in that when a rod of soft iron, exposed to longitudinal magnetizing force, is twisted, its magnetism is reduced.

Villari effect; really a reciprocal Joule effect. The susceptibility of an iron wire is increased by stretching when the magnetism is below a certain value, but diminished when above that value.

TABLE 550.—Magnetic Properties of Various Types of Iron and Steel

From tests made at the Bureau of Standards. *B* and *H* are measured in cgs units.

Values of *B*		2000	4000	6000	8000	10,000	12,000	14,000	16,000	18,000	20,000
Annealed Norway iron	H	.81	1.15	1.60	2.18	3.06	4.45	7.25	23.5	116.	—
	μ	2470	3480	3750	3670	3270	2700	1930	680	150	—
Cast semi-steel......	H	2.00	2.90	4.30	6.46	9.82	15.1	24.9	50.5	135.	325.
	μ	1000	1380	1400	1240	1020	795	563	317	133	62.
Machinery steel......	H	5.0	8.8	13.1	18.6	25.8	35.8	50.5	76.0	142.	—
	μ	400	455	460	430	390	340	280	210	127	—

TABLE 551.—Magnetic Properties of a Specimen of Very Pure Iron (.017% C)

From tests at the Bureau of Standards. *B* and *H* are measured in cgs units.

Values of *B*		2000	4000	6000	8000	10,000	12,000	14,000	16,000	18,000	20,000
Very pure iron as received	H	3.30	4.48	6.35	9.10	13.0	18.9	28.8	47.0	103.	240.
	μ	606	893	945	880	770	635	486	340	175	83
Annealed in vacuo from 900° C	H	.46	.60	.80	1.02	1.38	2.00	3.20	11.3	72.0	194.
	μ	4350	6670	7500	7840	7250	6000	4380	1420	250	103

As received:		After annealing:	
H_{max}	150	H_{max}	150
B_{max}	18,900	B_{max}	19,500
B_r	7,650		—
H_c	2.8	H_c	0.53

TABLE 552.—Magnetic Properties of Electrical Sheets

From tests at the Bureau of Standards. *B* and *H* are measured in cgs units.

Values of *B*		2000	4000	6000	8000	10,000	12,000	14,000	16,000	18,000	20,000
Dynamo steel.......	H	1.00	1.10	1.43	2.00	3.10	4.95	9.20	34.0	114.	—
	μ	2000	3640	4200	4000	3220	2420	1520	470	158	—
Ordinary transformer steel	H	.60	.87	1.10	1.48	2.28	3.85	10.9	43.0	149.	—
	μ	3340	4600	5450	5400	4380	3120	1280	372	121	—
High silicon transformer steel	H	.50	.70	.90	1.28	1.99	3.60	9.80	47.4	165.	—
	μ	4000	5720	6670	6250	5020	3340	1430	338	109	—

TABLE 553.—Magnetic Properties of Two Types of American Magnet Steel

From tests at the Bureau of Standards. B and H are measured in cgs units.

Values of B		2000	4000	6000	8000	10,000	12,000	14,000	16,000	18,000	20,000
Tungsten steel.	H	35.0	53.3	63.3	72.0	83.4	109	200	—	—	—
	μ	57	75	95	111	120	110	70	—	—	—
Chrome steel...	H	34.5	49.0	63.5	88.4	143	270	—	—	—	—
	μ	58	82	95	91	70	45	—	—	—	—

Percentage composition: Tungsten steel, C 0.67 W 5.1 Mn 0.38 Si 0.26
Chrome steel, C 0.81 W 0.96 Cr 2.09 Si 0.25

Tungsten steel: Hmax 200 Bmax 14,000 Chrome steel: Hmax 200 Bmax 11.050
H_c 62.5 B_r 10,400 H_c 45.7 B_r 7,030

TABLE 554.—Magnetic Properties of a Ferro-Cobalt Alloy, Fe_2Co (35% Cobalt)

From tests at the Bureau of Standards. B and H are measured in cgs units.

Values of B		2000	4000	6000	8000	10,000	12,000	14,000	16,000	18,000	20,000
As received.....	H	3.10	4.28	5.50	7.17	9.65	13.4	19.1	27.3	40.0	65.0
	μ	645	935	1090	1115	1040	900	730	590	450	310
Annealed at 1000° C	H	3.00	4.11	5.05	6.45	8.40	11.3	15.4	21.9	31.7	50.6
	μ	670	970	1190	1240	1190	1060	910	730	570	400
Quenched from 1000° C	H	10.8	13.8	19.1	28.7	43.4	65.8	104	163	262	—
	μ	185	290	314	279	230	182	135	98	69	—

	Bmax	Hmax	B_r	H_c
As received	15,000	22.9	7750	3.79
Annealed at 1000° C	15,000	18.3	7460	3.95
Quenched from 1000° C	15,000	130	8240	14.3

TABLE 555.—Magnetic Properties of a Ring Sample of Transformer Steel in Very Weak Fields

From tests made at the Bureau of Standards. B and H are measured in cgs units.

Values of H..........	0.001	0.002	0.004	0.006	0.008	0.010	0.012	0.014	0.018	0.020
Values of B..........	0.45	0.91	1.85	2.87	3.94	5.05	6.30	7.51	10.19	11.64
Values of μ..........	450	455	462	478	492	505	525	536	566	582

TABLE 556.—Magnetic Properties of Iron in Very Weak Fields

The effect of very small magnetizing forces has been studied by C. Baur and by Lord Rayleigh. The following short table is taken from Baur's paper, and is taken by him to indicate that the susceptibility is finite for zero values of H and for a finite range increases in simple proportion to H. He gives the formula $k = 15 + 100H$, or $I = 15H + 100H^2$ The experiments were made on an annealed ring of round bar 1.013 cms radius, the ring having a radius of 9.432 cms. Lord Rayleigh's results for an iron wire not annealed give $k = 6.4 + 5.1H$, or $I = 6.4H + 5.1H^2$. The forces were reduced as low as 0.00004 cgs, the relation of k to H remaining constant.

First experiment.			Second experiment.	
H	k	I	H	k
.01580	16.46	2.63	.0130	15.50
.03081	17.65	5.47	.0847	18.38
.07083	23.00	16.33	.0946	20.49
.13188	28.90	38.15	.1864	25.07
.23011	39.81	91.56	.2903	32.40
.38422	58.56	224.87	.3397	35.20

COMPOSITION AND MAGNETIC

This table and Table 558 below are taken from a paper by Dr. Hopkinson * on the magnetic properties of iron and steel
which is stated in the paper to have been 240. The maximum magnetization is not tabulated; but as stated in the
by 4π. "Coercive force" is the magnetizing force required to reduce the magnetization to zero. The "demag-
previous magnetization in the opposite direction to the "maximum induction" stated in the table. The "energy
which, however, was only found to agree roughly with the results of experiment.

No. of Test.	Description of specimen.	Temper.	Chemical analysis.					
			Total Carbon.	Manga-nese.	Sulphur.	Silicon.	Phos-phorus.	Other substances.
1	Wrought iron	Annealed	–	–	–	–	–	–
2	Malleable cast iron	"	–	–	–	–	–	–
3	Gray cast iron	–	–	–	–	–	–	–
4	Bessemer steel	–	0.045	0.200	0.030	None	0.040	–
5	Whitworth mild steel	Annealed	0.090	0.153	0.016	"	0.042	–
6	" "	"	0.320	0.438	0.017	0.042	0.035	–
7	" "	Oil-hardened	"	"	"	"	"	–
8	" "	Annealed	0.890	0.165	0.005	0.081	0.019	–
9	" "	Oil-hardened	"	"	"	"	"	–
10	Hadfield's manganese steel	–	1.005	12.360	0.038	0.204	0.070	–
11	Manganese steel	As forged	0.674	4.730	0.023	0.608	0.078	–
12	" "	Annealed	"	"	"	"	"	–
13	" "	Oil-hardened	"	"	"	"	"	–
14	" "	As forged	1.298	8.740	0.024	0.094	0.072	–
15	" "	Annealed	"	"	"	"	"	
16	" "	Oil-hardened	"	"	"	"	"	–
17	Silicon steel	As forged	0.685	0.694	"	3.438	0.123	–
18	" "	Annealed	"	"	"	"	"	–
19	" "	Oil-hardened	"	"	"	"	"	–
20	Chrome steel	As forged	0.532	0.393	0.020	0.220	0.041	0.621 Cr.
21	" "	Annealed	"	"	"	"	"	"
22	" "	Oil-hardened	"	"	"	"	"	"
23	" "	As forged	0.687	0.028	"	0.134	0.043	1.195 Cr.
24	" "	Annealed	"	"	"	"	"	"
25	" "	Oil-hardened	"	"	"	"	"	"
26	Tungsten steel	As forged	1.357	0.036	None.	0.043	0.047	4.649 W.
27	" "	Annealed	"	"	"	"	"	"
28	" "	Hardened in cold water	"	"	"	"	"	"
29	" "	Hardened in tepid water	"	"	"	"	"	"
30	" " (French)	Oil-hardened	0.511	0.625	None.	0.021	0.028	3.444 W.
31	" "	Very hard	0.855	0.312	–	0.151	0.089	2.353 W.
32	Gray cast iron	–	3.455	0.173	0.042	2.044	0.151	2.064 C.†
33	Mottled cast iron	–	2.581	0.610	0.105	1.476	0.435	1.477 C.†
34	White " "	–	2.036	0.386	0.467	0.764	0.458	–
35	Spiegeleisen	–	4.510	7.970	Trace.	0.502	0.128	–

* Phil. Trans. Roy. Soc. vol. 176.

† Graphitic carbon.

PROPERTIES OF IRON AND STEEL

The numbers in the columns headed "magnetic properties" give the results for the highest magnetizing force used, paper, it may be obtained by subtracting the magnetizing force (240) from the maximum induction and then dividing netizing force" is the magnetizing force which had to be applied in order to leave no residual magnetization after dissipated" was calculated from the formula: — Energy dissipated = coercive force × maximum induction ÷ π

No. of Test.	Description of specimen.	Temper.	Specific electrical resistance.	Magnetic properties.				Energy dissipated per cycle.
				Maximum induction.	Residual induction.	Coercive force.	Demagnetizive force.	
1	Wrought iron . . .	Annealed	.01378	18251	7248	2.30	–	13356
2	Malleable cast iron . .	"	.03254	12408	7479	8.80	–	34742
3	Gray cast iron . . .	–	.10560	10783	3928	3.80	–	13037
4	Bessemer steel . . .	–	.01050	18196	7860	2.96	–	17137
5	Whitworth mild steel .	Annealed	.01080	19840	7080	1.63	–	10289
6	" " .	"	.01446	18736	9840	6.73	–	40120
7	" " .	Oil-hardened	.01390	18796	11040	11.00	–	65786
8	" " .	Annealed	.01559	16120	10740	8.26	–	42366
9	" " .	Oil-hardened	.01695	16120	8736	19.38	–	99401
10	Hadfield's manganese steel .	–	.06554	310	–	–		–
11	Manganese steel . .	As forged	.05368	4623	2202	23.50	37.13	34567
12	" " . .	Annealed	.03928	10578	5848	33.86	46.10	113963
13	" " . .	Oil-hardened	.05556	4769	2158	27.64	40.29	41941
14	" " . .	As forged	.06993	747	–	–	–	–
15	" " . .	Annealed	.06316	1985	540	24.50	50.39	15474
16	" " . .	Oil-hardened	.07066	733	–	–	–	–
17	Silicon steel . . .	As forged	.06163	15148	11073	9.49	12.60	45740
18	" " . . .	Annealed	.06185	14701	8149	7.80	10.74	36485
19	" " . . .	Oil-hardened	.06195	14696	8084	12.75	17.14	59619
20	Chrome steel . . .	As forged	.02016	15778	9318	12.24	13.87	61439
21	" " . . .	Annealed	.01942	14848	7570	8.98	12.24	42425
22	" " . . .	Oil-hardened	.02708	13960	8595	38.15	48.45	169455
23	" " . . .	As forged	.01791	14680	7568	18.40	22.03	85944
24	" " . . .	Annealed	.01849	13233	6489	15.40	19.79	64842
25	" " . . .	Oil-hardened	.03035	12868	7891	40.80	56.70	167050
26	Tungsten steel . . .	As forged	.02249	15718	10144	15.71	17.75	78568
27	" " . . .	Annealed	.02250	16498	11008	15.30	16.93	80315
28	" " . . .	Hardened in cold water	.02274	–	–	–	–	–
29	" " . . .	Hardened in tepid water	.02249	15610	9482	30.10	34.70	149500
30	" " (French) .	Oil hardened	.03604	14480	8643	47.07	64.46	216864
31	" " . . .	Very hard	.04427	12133	6818	51.20	70.69	197660
32	Gray cast iron . . .	–	.11400	9148	3161	13.67	17.03	39789
33	Mottled cast iron . .	–	.06286	10546	5108	12.24	–	41072
34	White " " . .	–	.05661	9342	5554	12.24	20.40	36383
35	Spiegeleisen . . .	–	.10520	385	77	–	–	–

TABLE 558.—Permeability of Some of the Specimens in Table 557

This table gives the induction and the permeability for different values of the magnetizing force of some of the specimens in Table 557. The specimen numbers refer to the same table. The numbers in this table have been taken from the curves given by Dr. Hopkinson, and may therefore be slightly in error; they are the mean values for rising and falling magnetizations.

Magnetizing force. H	Specimen 1 (iron).		Specimen 8 (annealed steel).		Specimen 9 (same as 8 tempered).		Specimen 3 (cast iron).	
	B	μ	B	μ	B	μ	B	μ
1	–	–	–	–	–	–	265	265
2	200	100	–	–	–	–	700	350
3	–	–	–	–	–	–	1625	542
5	10050	2010	1525	300	750	150	3000	600
10	12550	1255	9000	900	1650	165	5000	500
20	14550	727	11500	575	5875	294	6000	300
30	15200	507	12650	422	9875	329	6500	217
40	15800	395	13300	332	11600	290	7100	177
50	16000	320	13800	276	12000	240	7350	149
70	16360	234	14350	205	13400	191	7900	113
100	16800	168	14900	149	14500	145	8500	85
150	17400	116	15700	105	15800	105	9500	63
200	17950	90	16100	80	16100	80	10190	51

Tables 559-563 give the results of some experiments by Du Bois,* on the magnetic properties of iron, nickel, and cobalt under strong magnetizing forces. The experiments were made on ovoids of the metals 18 centimeters long and 0.6 centimeters diameter. The specimens were as follows: (1) Soft Swedish iron carefully annealed and having a density 7.82. (2) Hard English cast steel yellow tempered at 230° C; density 7.78. (3) Hard drawn best nickel containing 99 % Ni with some SiO_2 and traces of Fe and Cu; density 8.82. (4) Cast cobalt giving the following composition on analysis: Co = 93.1, Ni = 5.8, Fe = 0.8, Cu = 0.2, Si = 0.1, and C = 0.3. The specimen was very brittle and broke in the lathe, and hence contained a surfaced joint held together by clamps during the experiment. Referring to the columns, H, B, and μ have the same meaning as in the other tables, S is the magnetic moment per gram, and I the magnetic moment per cubic centimeter. H and S are taken from the curves published by Du Bois; the others have been calculated using the densities given.

TABLE 559.—Magnetic Properties of Soft Iron at 0° and 100° C

Soft iron at 0° C.					Soft iron at 100° C.				
H	S	I	B	μ	H	S	I	B	μ
100	180.0	1408	17790	177.9	100	180.0	1402	17720	177.2
200	194.5	1521	19310	96.5	200	194.0	1511	19190	96.0
400	208.0	1627	20830	52.1	400	207.0	1613	20660	51.6
700	215.5	1685	21870	31.2	700	213.4	1663	21590	29.8
1000	218.0	1705	22420	22.4	1000	215.0	1674	22040	21.0
1200	218.5	1709	22670	18.9	1200	215.5	1679	22300	18.6

TABLE 560.—Magnetic Properties of Steel at 0° and 100° C

Steel at 0° C.					Steel at 100° C.				
H	S	I	B	μ	H	S	I	B	μ
100	165.0	1283	16240	162.4	100	165.0	1278	16170	161.7
200	181.0	1408	17900	89.5	200	180.0	1395	17730	88.6
400	193.0	1500	19250	48.1	400	191.0	1480	19000	47.5
700	199.5	1552	20210	28.9	700	197.0	1527	19890	28.4
1000	203.5	1583	20900	20.9	1000	199.0	1543	20380	20.4
1200	205.0	1595	21240	17.7	1500	203.0	1573	21270	14.2
3750†	212.0	1650	24470	6.5	3000	205.5	1593	23020	7.7
					5000	208.0	1612	25260	5.1

* "Phil. Mag." 5 series, vol. xxix.

† The results in this and the other tables for forces above 1200 were not obtained from the ovoids above referred to, but from a small piece of the metal provided with a polished mirror surface and placed, with its polished face normal to the lines of force, between the poles of a powerful electromagnet. The induction was then inferred from the rotation of the plane of a polarized ray of red light reflected normally from the surface. (See Kerr's "Constants," p. 480.)

MAGNETIC PROPERTIES OF METALS

TABLE 561.—Cobalt at 0° and 100° C

H	S	I	B	μ
200	106	848	10850	54.2
300	116	928	11960	39.9
500	127	1016	13260	26.5
700	131	1048	13870	19.8
1000	134	1076	14520	14.5
1500	138	1104	15380	10.3
2500	143	1144	16870	6.7
4000	145	1164	18630	4.7
6000	147	1176	20780	3.5
9000	149	1192	23980	2.6
At 0° C this specimen gave the following results:				
7900	154	1232	23380	3.0

TABLE 562.—Nickel at 0° and 100° C

H	S	I	B	μ
100	35.0	309	3980	39.8
200	43.0	380	4966	24.8
300	46.0	406	5399	18.0
500	50.0	441	6043	12.1
700	51.5	454	6409	9.1
1000	53.0	468	6875	6.9
1500	56.0	494	7707	5.1
2500	58.4	515	8973	3.6
4000	59.0	520	10540	2.6
6000	59.2	522	12561	2.1
9000	59.4	524	15585	1.7
12000	59.6	526	18606	1.5
At 0° C this specimen gave the following results:				
12300	67.5	595	19782	1.6

TABLE 563.—Magnetite

The following results are given by Du Bois * for a specimen of magnetite.

H	I	B	μ
500	325	4580	9.16
1000	345	5340	5.34
2000	350	6400	3.20
12000	350	16400	1.37

Professor Ewing has investigated the effects of very intense fields on the induction in iron and other metals.† The results show that the intensity of magnetization does not increase much in iron after the field has reached an intensity of 1000 c. g. s. units, the increase of induction above this being almost the same as if the iron were not there, that is to say, dB/dH is practically unity. For hard steels, and particularly manganese steels, much higher forces are required to produce saturation. Hadfield's manganese steel seems to have nearly constant susceptibility up to a magnetizing force of 10,000. The following tables, taken from Ewing's papers, illustrate the effects of strong fields on iron and steel. The results for nickel and cobalt do not differ greatly from those given above.

TABLE 564.—Lowmoor Wrought Iron

H	I	B	μ
3080	1680	24130	7.83
6450	1740	28300	4.39
10450	1730	32250	3.09
13600	1720	35200	2.59
16390	1630	36810	2.25
18760	1680	39900	2.13
18980	1730	40730	2.15

TABLE 565.—Vicker's Tool Steel

H	I	B	μ
6210	1530	25480	4.10
9970	1570	29650	2.97
12120	1550	31620	2.60
14660	1580	34550	2.36
15530	1610	35820	2.31

TABLE 566.—Hadfield's Manganese Steel

H	I	B	μ
1930	55	2620	1.36
2380	84	3430	1.44
3350	84	4400	1.31
5920	111	7310	1.24
6620	187	8970	1.35
7890	191	10290	1.30
8390	263	11690	1.39
9810	396	14790	1.51

TABLE 567.—Saturation Values for Steels

		H	I	B	μ
1	Bessemer steel containing about 0.4 per cent carbon . . .	17600	1770	39880	2.27
2	Siemens-Marten steel containing about 0.5 per cent carbon	18000	1660	38860	2.16
3	Crucible steel for making chisels, containing about 0.6 per cent carbon	19470	1480	38010	1.95
4	Finer quality of 3 containing about 0.8 per cent carbon . .	18330	1580	38190	2.08
5	Crucible steel containing 1 per cent carbon	19620	1440	37690	1.92
6	Whitworth's fluid-compressed steel	18700	1590	38710	2.07

* "Phil. Mag." 5 series, vol. xxix, 1890.

† "Phil. Trans. Roy. Soc." 1885 and 1889.

DEMAGNETIZING FACTORS FOR RODS

TABLE 568

H = true intensity of magnetizing field, H' = intensity of applied field, I = intensity of magnetization, $H = H' - NI$.

Shuddemagen says: The demagnetizing factor is not a constant, falling for highest values of I to about 1/7 the value when unsaturated; for values of B ($= H + 4\pi I$) less than 10000, N is approximately constant; using a solenoid wound on an insulating tube, or a tube of split brass, the reversal method gives values for N which are considerably lower than those given by the step-by-step method; if the solenoid is wound on a thick brass tube, the two methods practically agree.

Ratio of Length to Diameter.	Values of $N \times 10^4$.						
		Cylinder.					
				Ballistic Step Method.			
	Ellipsoid.	Uniform Magnetization.	Magnetometric Method (Mann).	Dubois.	Shuddemagen for Range of Practical Constancy.		
				Diameter.			
				0.158 cm.	0.3175 cm.	1.111 cm.	1.905 cm.
5	7015	–	6800				
10	2549	630	2550	2160	–	–	1960
15	1350	280	1400	1206	–	–	1075
20	848	160	898	775	–	–	671
30	432	70	460	393	388	350	343
40	266	39	274	238	234	212	209
50	181	25	182	162	160	145	149
60	132	18	131	118	116	106	106
70	101	13	99	89	88		
80	80	9.8	78	69	69	66	63
90	65	7.8	63	55	56		
100	54	6.3	51.8	45	46	41	41
150	26	2.8	25.1	20	23	21	21
200	16	1.57	15.2	11	12.5	11	11
300	7.5	0.70	7.5	5.0			
400	4.5	0.39	–	2.8			

C. R. Mann, Physical Review, 3, p. 359; 1896.
H. DuBois, Wied. Ann. 7, p. 942; 1902.
C. L. B. Shuddemagen, Proc. Am Acad Arts and Sci. 43, p. 185, 1907 (Bibliography).

TABLE 569

Shuddemagen also gives the following, where K is determined by the step method and $H = H' - KB$.

Ratio of Length to Diameter.	Values of $K \times 10^4$.	
	Diameter 0.3175 cm.	Diameter 1.1 to 2.0 cm.
15	–	85.2
20	–	53.3
25	–	36.6
30	30.9	27.3
40	18.6	16.6
50	12.7	11.6
60	9.25	8.45
80	5.5	5.05
100	3.66	3.26
150	1.83	1.67

TABLE 570.—Magnetic Properties of Iron and Steel

	Electrolytic Iron.	Good Cast Steel.	Poor Cast Steel.	Steel.	Cast Iron.	Electrical Sheets. Ordinary.	Electrical Sheets. Silicon Steel.
Chemical composition in per cent C	0.024	0.044	0.56	0.99	3.11	0.036	0.036
Si	0.004	0.004	0.18	0.10	3.27	0.330	3.90
Mn	0.008	0.40	0.29	0.40	0.56	0.260	0.090
P	0.008	0.044	0.076	0.04	1.05	0.040	0.009
S	0.001	0.027	0.035	0.07	0.06	0.068	0.006
Coercive force	2.83 [0.36]	1.51 [0.37]	7.1 (44.3)	16.7 (52.4)	11.4 [4.6]	[1.30]	[0.77]
Residual B	11400 [10800]	10600 [11000]	10500 (10500)	13000 (7500)	5100 [5350]	[9400]	[9850]
Maximum permeability	1850 [14400]	3550 [14800]	700 (170)	375 (110)	240 [600]	[3270]	[6130]
B for H=150	19200 [18900]	18800 [19100]	17400 (15400)	16700 (11700)	10400 [11000]	[18200]	[17550]
$4\pi I$ for saturation	21620 [21630]	21420 [21420]	20600 (20200)	19800 (18000)	16400 [16800]	[20500]	[19260]

E Gumlich, Zs für Electrochemie, 15, p. 599; 1909

Brackets indicate annealing at 800° C in vacuum. *Parentheses* indicate hardening by quenching from cherry-red.

TABLE 571.—Cast Iron in Intense Fields

Soft Cast Iron. H	B	I	μ	Hard Cast Iron. H	B	I	μ
114	9950	782	87.3	142	7860	614	55.4
172	10800	846	62.8	254	9700	752	38.2
433	13900	1070	32.1	339	10850	836	30.6
744	15750	1200	21.2	684	13050	983	19.1
1234	17300	1280	14.0	915	14050	1044	15.4
1820	18170	1300	10.0	1570	15900	1138	10.1
12700	31100	1465	2.5	2020	16800	1176	8.3
13550	32100	1475	2.4	10900	26540	1245	2.4
13800	32500	1488	2.4	13200	28600	1226	2.2
15100	33650	1472	2.2	14800	30200	1226	2.0

B. O. Peirce, Proc. Am. Acad. 44, 1909.

TABLE 572.—Corrections for Ring Specimens

In the case of ring specimens, the average magnetizing force is not the value at the mean radius, the ratio of the two being given in the table. The flux density consequently is not uniform, and the measured hysteresis is less than it would be for a uniform distribution. This ratio is also given for the case of constant permeability, the values being applicable for magnetizations in the neighborhood of the maximum permeability. For higher magnetizations the flux density is more uniform, for lower it is less, and the correction greater.

Ratio of Radial Width to Diameter of Ring.	Ratio of Average H to H at Mean Radius. Rectangular Cross-section.	Ratio of Average H to H at Mean Radius. Circular Cross-section.	Ratio of Hysteresis for Uniform Distribution to Actual Hysteresis. Rectangular Cross-section.	Ratio of Hysteresis for Uniform Distribution to Actual Hysteresis. Circular Cross-section.
1/2	1.0986	1.0718	1.112	1.084
1/3	1.0397	1.0294	1.045	1.033
1/4	1.0216	1.0162	1.024	1.018
1/5	1.0137	1.0102	1.015	1.011
1/6	1.0094	1.0070	1.010	1.008
1/7	1.0069	1.0052	1.008	1.006
1/8	1.0052	1.0040	1.006	1.004
1/10	1.0033	1.0025	1.003	1.002
1/19	1.0009	1.0007	1.001	1.001

M. G. Lloyd, Bull. Bur. Standards, 5, p 435; 1908.

TABLE 573.—Energy Losses in Transformer Steels

Determined by the wattmeter method.

Loss per cycle per $cc = AB^x + bnB^y$, where B = flux density in gausses and n = frequency in cycles per second. x shows the variation of hysteresis with B between 5000 and 10000 gausses, and y the same for eddy currents.

Designation.	Thickness. cm.	Ergs per Gramme per Cycle. 10000 Gausses. Hysteresis.	10000 Gausses. Eddy Currents at 60~	5000 Gausses. Hysteresis.	5000 Gausses. Eddy Currents at 60~	x	y	a	Watts per Pound at 60 Cycles and 10000 Gausses. Eddy Current Loss for Gage No. 29 ‡	Hysteresis.	Total.
Unannealed											
A	0.0399	1599	186	562	46	1.51	2.02	0.00490	0.41	4.35	4.76
B	.0326	1156	134	384	36	1.59	1.89	.00358	0.44	3.14	3.58
C	.0422	1032	242	356	70	1.51	1.79	.00319	0.47	2.81	3.28
D	.0381	1009	184	353	48	1.52	1.94	.00312	0.44	2.74	3.18
Annealed											
E	.0476	735	236	246	58	1.58	2.02	.00227	0.36	2.00	2.36
F	.0280	666	100	220	27	1.60	1.88	.00206	0.44	1.81	2.25
G	.0394	563	210	193	54	1.54	1.96	.00174	0.47	1.53	2.00
H*	.0307	412	146	138.5	39	1.58	1.90	.00127	0.54	1.12	1.66
J	.0318	341	202	111.5	55	1.62	1.88	.00105	0.70	0.93	1.63
K*	.0282	394	124	130	32	1.61	1.90	.00122	0.54	1.07	1.61
L	.0346	381	184	125	50	1.61	1.88	.00118	0.535	1.035	1.57
B	.0338	354	200	116	57	1.61	1.81	.00110	0.61	0.96	1.57
M	.0335	372	178	127	46	1.55	1.95	.00115	0.55	1.01	1.56
N	.0340	321	210	105	56	1.62	1.90	.00099	0.63	0.87	1.50
P	.0437	334	184	107	50	1.64	1.88	.00103	0.34	0.91	1.25
Silicon steels											
Q†	.0361	303	54	98	15	1.63	–	.00094	0.14	0.825	0.965
R	.0315	288	42	93	11	1.64	–	.00089	0.15	0.78	0.93
S	.0452	278	72	90	18	1.63	–	.00086	0.12	0.755	0.875
T	.0338	250	60	78	18	1.68	–	.00077	0.18	0.68	0.86
U	.0346	270	42	86	12	1.66	–	.00084	0.12	0.735	0.855
V*	.0310	251.5	47	79	13	1.68	–	.00078	0.17	0.685	0.855
W*	.0305	197	43	62.3	12.4	1.67	–	.00061	0.16	0.535	0.695
X	.0430	200	65	64.2	16.6	1.65	–	.00062	0.12	0.545	0.665

* German. † English.

‡ In order to make a fair comparison, the eddy current loss has been computed for a thickness of 0.0357 cm (Gage No. 29), assuming the loss proportional to the thickness.

Lloyd and Fisher, Bull. Bur. Standards, 5, p. 453; 1909.

Note. — For formulæ and tables for the calculation of mutual and self inductance see Bulletin Bureau of Standards, vol. 8, p. 1–237, 1912.

TABLE 574.—Magnetic Properties of Permalloy

(Yensen, Nickel-Iron Alloys, Journ. Franklin Inst., 199, 340, 1925; Arnold, Elmen, Permalloy, loc. cit., 195, 621, 1923.)

Alloy	Permeability Initial B/H $H=0$	Permeability B/H max.	Saturation 4I (gausses)	Hysteresis B = 10000 Erg/C³ /cycle	Retentivity gausses	Coercive force gilbert/cm	Electrical resistance microhms per cm³ 20°C	Density
Fe, 3 mm thick	700	26,000	22,600	600	8,600	0.20	10	7.9
4% Si, .35 mm thick	440	15,500	20,000	500	5,200	.15	55	7.6
50% Ni, .35 mm thick*	3,000	70,000	15,500	220	7,300	.05	46	8.3
78% Ni, .35 mm thick	5,850	74,000	10,500	200	5,500	.05	21	8.6

* Permalloy.

DISSIPATION OF ENERGY IN THE CYCLIC MAGNETIZATION OF VARIOUS SUBSTANCES

C. P. Steinmetz concludes from his experiments * that the dissipation of energy due to hysteresis in magnetic metals can be expressed by the formula $e = aB^{1.6}$, where e is the energy dissipated and a a constant. He also concludes that the dissipation is the same for the same range of induction, no matter what the absolute value of the terminal inductions may be. His experiments show this to be nearly true when the induction does not exceed $\pm$ 15000 c. g. s. units per sq. cm. It is possible that, if metallic induction only be taken, this may be true up to saturation ; but it is not likely to be found to hold for total inductions much above the saturation value of the metal. The law of variation of dissipation with induction range in the cycle, stated in the above formula, is also subject to verification.†

Values of Constant a

The following table gives the values of the constant a as found by Steinmetz for a number of different specimens. The data are taken from his second paper.

Number of specimen.	Kind of material.	Description of specimen.	Value of a.
1	Iron . .	Norway iron	.00227
2	" . .	Wrought bar	.00326
3	" . .	Commercial ferrotype plate	.00548
4	" . .	Annealed " "	.00458
5	" . .	Thin tin plate	.00286
6	" . .	Medium thickness tin plate	.00425
7	Steel . .	Soft galvanized wire	.00349
8	" . .	Annealed cast steel	.00848
9	" . .	Soft annealed cast steel	.00457
10	" . .	Very soft annealed cast steel	.00318
11	" . .	Same as 8 tempered in cold water	.02792
12	" . .	Tool steel glass hard tempered in water . .	.07476
13	" . .	" " tempered in oil	.02670
14	" . .	" " annealed	.01899
15	" . .	Same as 12, 13, and 14, after having been subjected to an alternating m. m. f. of from 4000 to 6000 ampere turns for demagnetization	.06130
16	" . .		.02700
17	" . .		.01445
18	Cast iron .	Gray cast iron	.01300
19	" " .	" " " containing $\frac{1}{8}$ % aluminium . .	.01365
20	" " .	" " " " $\frac{1}{2}$ % " . .	.01459
21	Magnetite .	A square rod 6 sq. cms. section and 6.5 cms. long, from the Tilly Foster mines, Brewsters, Putnam County, New York, stated to be a very pure sample	.02348
22	Nickel .	Soft wire	.0122
23	" .	Annealed wire, calculated by Steinmetz from Ewing's experiments	.0156
24	" .	Hardened, also from Ewing's experiments . .	.0385
25	Cobalt .	Rod containing about 2 % of iron, also calculated from Ewing's experiments by Steinmetz . .	.0120
26	Iron filings	Consisted of thin needle-like chips obtained by milling grooves about 8 mm. wide across a pile of thin sheets clamped together. About 30 % by volume of the specimen was iron.	
		1st experiment, continuous cyclic variation of m. m. f. 180 cycles per second	.0457
		2d experiment, 114 cycles per second . . .	.0396
		3d " 79–91 cycles per second . . .	.0373

* "Trans. Am. Inst. Elect. Eng." January and September, 1892.
† See T. Gray, "Proc. Roy. Soc." vol. lvi.

TABLE 576.—Magnetism and Temperature, Critical Temperature

The magnetic moment of a magnet diminishes with increasing temperature. Different specimens vary widely. In the formula $Mt/M_0 = (1 - at)$ the value of a may range from .0003 to .001 (see Tables 559-560). The effect on the permeability with weak fields may at first be an increase. There is a critical temperature (Curie point) above which the permeability is very small (paramagnetic?). Diamagnetic susceptibility does not change with the temperature. Paramagnetic susceptibility decreases with increase in temperature. This and the succeeding two tables are taken from Dushman, "Theories of Magnetism," General Electric Review, 1916.

Substance.	Critical temperature, Curie point.	Reference.	Substance.	Critical temperature, Curie point.	Reference.
Iron, α form	756° C	1	MnBi	360 to 380° C	4
" β form	920	1	MnSb	310 " 320	4
" γ form	1280	1	MnAs	45 " 50	4
Magnetite (Fe_3O_4)	536	1	MnP	18 " 25	4
"	589	2	Heusler alloy	310	5
"	555	3	Nickel	340	1
Cobalt-ferrite (Fe_2Co)	520	3	"	376	6
			Cobalt	1075	6

References: (1) P. Curie; (2) see Williams, Electron Theory of Magnetism, quoted from Weiss; (3) du Bois, Tr. Far. Soc. 8, 211, 1912; (4) Hilpert, Tr. Far. Soc. 8, 207, 1912; (5) Gumaer; (6) Stifler, Phys. Rev. 33, 268, 1911.

TABLE 577.—Temperature Variation for Paramagnetic Substances

The relation deduced by Curie that $\chi = C/T$, where C is a constant and T the absolute temperature, holds for some paramagnetic substances over the ranges given in the following table. Many paramagnetic substances do not obey the law (Honda and Owen, Ann. d. Phys. 32, 1027, 1910; 37, 657, 1912). See the following table.

Substance.	$C \times 10^6$	Range ° C	Reference.	Substance.	$C \times 10^6$	Range ° C	Reference.
Oxygen	33,700	20° to 450° C	1	Gadolinium sulphate	21,000	−259° to 17	2
Air	7,830	— — —	1	Ferrous sulphate	11,000	−259 " 17	2
Palladium	1,520	20 to 1370	1	Ferric sulphate	17,000	−208 " 17	3
Magnetite	28,000	850 " 1360	1	Manganese chloride	30,000	−258 " 17	3
Cast iron	38,500	850 " 1267	1				

References: (1) P. Curie, London Electrician, 66, 500, 1912; see also Du Bois, Rap. du Cong. 2, 460, 1900; (2) Perrier, Onnes, Tables annuelles, 3, 288, 1914; (3) Oosterhuis, Onnes, *l.c.* 2, 389, 1913.

TABLE 578.—Temperature Effect on Susceptibility of Diamagnetic Elements

No effect:

B Cryst. 400 to 1200°	P white	Se —	Sb −170 to 50°
C Diamond, +170 to 200°	S Cryst.; ppt.	Br −170 to 18°	Cs and Au
C "Sugar" carbon	Zn −170 to 300°	Zr Cryst. −170 to 500°	Hg −39 to +350°
Si Cryst.	As —	Cd −170 to 300°	Pb 327 to 600°

Increase with rise in Temperature:

Be —	C Diamond, 200 to 1200°	I −170 to 114°
B Cryst. +170 to 400°	Ag —	Hg −170 to −30°

Decrease with rise in Temperature:

C Amorphous	Gd −179 to 30°	In −170 to 150°	Tl —
C Ceylon graphite	Ge −170 to 900°	Sb +50 to +631°	Pb −170 to 327°
Cu —	Zr 500 to 1200°	Te —	Bi −170 to 268°
Zn +300 to 700°	Cd 300 to 700°	I +114 to +200°	

TABLE 579.—Temperature Effect on Susceptibility of Paramagnetic Elements

No effect:

Li —	K −170 to 150°	Cr −170 to 500°	W —
Na −170 to 97°	Ca −170 to 18°	Mn −170 to 250°	Os —
Al 657 to 1100°	V −170 to 500°	Rb —	

Increase with rise in Temperature:

Ti −40 to 1100°	Cr 500 to 1100°	Ru +550 to 1200°	Ba −170 to 18°
V 500 to 1100°	Mo −170 to 1200°	Rh —	Ir and Th

Decrease with rise in Temperature:

(O) —	Ti −180 to −40°	Ni 350 to 800°	Pd and Ta
As −170 to 657°	Mn 250 to 1015°	Co above 1150°	Pt and U
Mg —	(Fe) —	Cb −170 to 400°	Rare earth metals

Tables 578 and 579 are due to Honda and Owen; for reference, see preceding table.

Table 580

MAGNETIC SUSCEPTIBILITY

If $\mathfrak{I}$ is the intensity of magnetization produced in a substance by a field strength $\mathfrak{H}$, then the magnetic susceptibility $H = \mathfrak{I}/\mathfrak{H}$. This is generally referred to the unit mass; italicized figures refer to the unit volume. The susceptibility depends greatly upon the purity of the substance, especially its freedom from iron. The mass susceptibility of a solution containing p per cent by weight of a water-free substance is, if H_0 is the susceptibility of water, $(p/100)\,H + (1 - p/100)\,H_0$.

Substance.	H × 10⁶	Temp. °C	Remarks
Ag	−0.19	18°	
AgCl	−0.28		
Air, 1 Atm.	*+0.024*	15	
Al	+0.65	18	
$Al_2K_2(SO_4)_4 24H_2O$	*−1.0*		Crys.
A, 1 Atm.	*−0.10*	0	
As	−0.3	18	
Au	−0.15	18	
B	−0.71	18	
$BaCl_2$	−0.36	20	
Be	+0.79	15	Powd.
Bi	−1.4	18	
Br	−0.38	18	
C, arc-carbon	−2.0	18	
C, diamond	−0.49	18	
CH_4, 1 Atm.	*+0.001*	16	
CO_2, 1 Atm.	*+0.002*	16	
CS_2	*−0.77*	18	
CaO	*−0.27*	16	Powd.
$CaCl_2$	−0.40	19	"
$CaCO_3$, marble	*−0.7*		
Cd	−0.17	18	
$CeBr_3$	+6.3	18	
Cl_2, 1 Atm.	−0.59	16	
$CoCl_2$	+90.	18	Sol'n
$CoBr_2$	+47.	18	"
CoI_2	+33.	18	"
$CoSO_4$	+57.	19	"
$Co(NO_3)_2$	+57.	18	"
Cr	+3.7	18	
CsCl	−0.28	17	Powd.
Cu	−0.09	18	
$CuCl_2$	+12.	20	Sol'n
$CuSO_4$	+10.	20	Sol'n
CuS	+0.16	17	Powd.
$FeCl_3$	+90.	18	Sol'n
$FeCl_2$	+90.	18	"
$FeSO_4$	+82.	20	"
$Fe_2(NO_3)_6$	+50.	18	"
$FeCn_6K_4$	−0.44		Powd.
$FeCn_6K_3$	+9.1		"
He, 1 Atm.	*−0.002*	0	
H_2, 1 Atm.	*0.000*	16	
H_2, 40 Atm.	*0.000*	16	
H_2O	−0.79	20	
HCl	*−0.80*	20	
H_2SO_4	*+0.78*	20	
HNO_3	*−0.70*	20	
Hg	−0.19	20	
I	−0.4	20	
In	0.1±	18	
Ir	+0.15	18	
K	+0.40	20	
KCl	−0.50	20	
KBr	−0.40	20	
KI	−0.38	20	
KOH	−0.35	22	Sol'n
K_2SO_4	−0.42	20	
$KMnO_4$	+2.0		
KNO_3	−0.33	20	
K_2CO_3	−0.50	20°	Sol'n
Li	+0.38		
Mo	+0.04	18	
Mg	+0.55	18	
$MgSO_4$	−0.40		
Mn	+11.	18	
$MnCl_2$	+122.	18	Sol'n
$MnSO_4$	+100.	18	"
N_2, 1 Atm.	*0.001*	16	
NH_3	−1.1		
Na	+0.51	18	
NaCl	−0.50	20	
Na_2CO_3	−0.19	17	Powd.
$Na_2CO_3 \cdot 10\,H_2O$	−0.46	17	"
Nb	+1.3	18	
$NiCl_2$	+40.	18	Sol'n
$NiSO_4$	+30.	20	"
O_2, 1 Atm.	+0.120	20	
Os	+0.04	20	
P, white	−0.90	20	
P, red	−0.50	20	
Pb	−0.12	20	
$PbCl_2$	−0.25	15	Powd.
Pd	+5.8	18	
$PrCl_3$	+13.	18	Sol'n
Pt	+1.1	18	
$PtCl_4$	0.0	22	Sol'n
Rh	+1.1	18	
S	−0.48	18	
SO_2, 1 Atm.	−0.30	16	
Sb	−0.94	18	
Se	−0.32	18	
Si	−0.12	18	Crys.
SiO_2, Quartz	−0.44	20	
—Glass	−0.5±		
Sn	+0.03	20	
$SrCl_2$	−0.42	20	Sol'n
Ta	+0.93	18	
Te	−0.32	20	
Th	+0.18	18	
Ti	+3.1	18	
Va	+1.5	18	
Wo	+0.33	20	
Zn	−0.15	18	
$ZnSO_4$	−0.40		
Zr	−0.45	18	
CH_3OH	−0.73		
C_2H_5OH	−0.80		
C_3H_7OH	−0.80		
$C_2H_5OC_2H_5$	*−0.60*	20	
$CHCl_3$	−0.58		
C_6H_6	−0.78		
Ebonite	*+1.1*		
Glycerine	−0.64	22	
Sugar	−0.57		
Paraffin	*−0.58*		
Petroleum	−0.91		
Toluene	−0.77		
Wood	−0.2–5		
Xylene	−0.81		

Values are mostly means taken of values given in Landolt-Börnstein's Physikalisch-chemische Tabellen. See especially Honda, Annalen der Physik (4), 32, 1910.

TABLE 581

MAGNETO-OPTIC ROTATION

GENERAL DISCUSSION

Faraday discovered that, when a piece of heavy glass is placed in magnetic field and a beam of plane polarized light passed through it in a direction parallel to the lines of magnetic force, the plane of polarization of the beam is rotated. This was subsequently found to be the case with a large number of substances, but the amount of the rotation was found to depend on the kind of matter and its physical condition, and on the strength of the magnetic field and the wave-length of the polarized light. Verdet's experiments agree fairly well with the formula —

$$\theta = clH\left(r - \lambda\frac{dr}{d\lambda}\right)\frac{r^2}{\lambda^2},$$

where c is a constant depending on the substance used, l the length of the path through the substance, H the intensity of the component of the magnetic field in the direction of the path of the beam, r the index of refraction, and λ the wave-length of the light in air. If H be different, at different parts of the path, lH is to be taken as the integral of the variation of magnetic potential between the two ends of the medium. Calling this difference of potential v, we may write $\theta = Av$, where A is constant for the same substance, kept under the same physical conditions, when the one kind of light is used. The constant A has been called "Verdet's constant," * and a number of values of it are given in Tables 582-586. For variation with temperature the following formula is given by Bichat: —

$$R = R_0\,(1 - 0.00104\,t - 0.000014\,t^2),$$

which has been used to reduce some of the results given in the table to the temperature corresponding to a given measured density. For change of wave-length the following approximate formula, given by Verdet and Becquerel, may be used: —

$$\frac{\theta_1}{\theta_2} = \frac{\mu_1^2(\mu_1^2 - 1)\lambda_2^2}{\mu_2^2(\mu_2^2 - 1)\lambda_1^2},$$

where μ is index of refraction and λ wave-length of light.

A large number of measurements of what has been called molecular rotation have been made, particularly for organic substances. These numbers are not given in the table, but numbers proportional to molecular rotation may be derived from Verdet's constant by multiplying in the ratio of the molecular weight to the density. The densities and chemical formulæ are given in the table. In the case of solutions, it has been usual to assume that the total rotation is simply the algebraic sum of the rotations which would be given by the solvent and dissolved substance, or substances, separately; and hence that determinations of the rotary power of the solvent medium and of the solution enable the rotary power of the dissolved substance to be calculated. Experiments by Quincke and others do not support this view, as very different results are obtained from different degrees of saturation and from different solvent media. No results thus calculated have been given in the table, but the qualitative result, as to the sign of the rotation produced by a salt, may be inferred from the table. For example, if a solution of a salt in water gives Verdet's constant less than 0.0130 at 20° C, Verdet's constant for the salt is negative.

The table has been for the most part compiled from the experiments of Verdet,† H. Becquerel,‡ Quincke,§ Koepsel,‖ Arons,¶ Kundt,** Jahn,†† Schönrock,‡‡ Gordon,§§ Rayleigh and Sidgewick,‖‖ Perkin,¶¶ Bichat.***

As a basis for calculation, Verdet's constant for carbon disulphide and the sodium line D has been taken as 0.0420 and for water as 0.0130 at 20° C.

* The constancy of this quantity has been verified through a wide range of variation of magnetic field by H. E. J. G. Du Bois (Wied. Ann. vol. 35), p. 137, 1888.
† "Ann. de Chim. et de Phys." [3] vol. 52, p. 129, 1858.
‡ "Ann. de Chim. et de Phys." [5] vol. 12; "C. R." vols 90, p. 1407, 1880, and 100, p. 1374, 1885.
§ "Wied. Ann." vol. 24, p. 606, 1885.
‖ "Wied. Ann." vol. 26, p. 456, 1885.
¶ "Wied. Ann." vol. 24, p. 161, 1885.
** "Wied. Ann." vols. 23, p. 228, 1884, and 27, p. 191, 1886.
†† "Wied. Ann." vol. 43, p. 280, 1891.
‡‡ "Zeits. für Phys. Chem." vol. 11, p. 753, 1893.
§§ "Proc. Roy. Soc." 36, p. 4, 1883.
‖‖ "Phil. Trans. R. S." 176, p. 343, 1885.
¶¶ "Jour. Chem. Soc."
*** "Jour. de Phys." vols. 8, p. 204, 1879, and 9, p. 204 and p. 275, 1880.

Table 582

MAGNETO-OPTIC ROTATION

Solids, Verdet's Constant

Substance.	Formula.	Wave-length.	Verdet's Constant. Minutes.	Temp. C.	Authority
		μ			
Amber		0.589	0.0095	18–20°	Quincke.
Blende	ZnS	"	0.2234	15	Becquerel.
Diamond	C	"	0.0127	15	"
Lead borate	PbB_2O_4	"	0.0600	15	"
Selenium	Se	0.687	0.4625	15	"
Sodium borate	$Na_2B_4O_7$	0.589	0.0170	15	"
Ziqueline (Cuprite)	Cu_2O	0.687	0.5908	15	"
Fluorite	$CaFl_2$	0.2534	0.05989	20	Meyer, Ann. der Physik, 30, 1909.
		.3655	.02526	"	
		.4358	.01717	"	
		.4916	.01329	"	
		.589	.00897	"	
		1.00	.00300	"	
		2.50	.00049	"	
		3.00	.00030	"	
Glass, Jena: Medium phosphate crn.		0.589	0.0161	18	DuBois, Wied. Ann. 51, 1894.
Heavy crown,	O1143	"	0.0220	"	
Light flint,	O451	"	0.0317	"	
Heavy flint	O500	"	0.0608	"	
" "	S163	"	0.0888	"	
Zeiss, Ultraviolet		0.313	0.0674	16	Landau, Phys. ZS. 9, 1908.
"		0.405	.0369	"	
"		0.436	.0311	"	
Quartz, along axis, i.e., plate cut ⊥ to axis	SiO_2	0.2194	0.1587	20	Borel, Arch. sc. phys. 16, 1903.
		.2573	.1079	"	
		.3609	.04617	"	
		.4800	.02574	"	
		.5892	.01664	"	
		.6439	.01368	"	
Rock salt	NaCl	0.2599	0.2708	20	Meyer, as above.
		.3100	.1561	"	
		.4046	.0775	"	
		.4916	.0483	"	
		.6708	.0245	"	
		1.00	.01050	"	
		2.00	.00262	"	
		4.00	.00069	"	
Sugar, cane: along axis IIA	$C_{12}H_{22}O_{11}$	0.451	.0122	20	Voigt, Phys. ZS. 9, 1908.
		.540	.0076	"	
		.626	.0066	"	
axis IIA[1]	–	0.451	0.0129	"	
		.540	.0084	"	
		.626	.0075	"	
Sylvite	KCl	0.4358	0.0534	20	Meyer, as above.
		.5461	.0316	"	
		.6708	.02012	"	
		.90	.01051	"	
		1.20	.00608	"	
		2.00	.00207	"	
		4.00	.00054	"	

MAGNETO-OPTIC ROTATION

TABLE 583.—Liquids, Verdet's Constant for λ = 0.589μ

Substance	Chemical formula	Density in grams per cm³	Verdet's constant in minutes	Temp. C	Authority
Acetone	C_3H_6O	0.7947	0.0113	20°	Jahn
Acids: Formic	CH_2O_2	1.2273	.0105	15	Perkin
Acetic	$C_2H_4O_2$	1.0561	.0105	21	"
Hydrochloric	HCl	1.2072	.0224	15	"
Hydrobromic	HBr	1.7859	.0343	"	"
Hydroiodic	HI	1.9473	.0515	"	"
Nitric	HNO_3	1.5190	.0070	13	"
Alcohols: Methyl	CH_3OH	.7920	.0093	20	Jahn
Ethyl	C_2H_5OH	.7900	.0112	"	"
Benzene	C_6H_6	.8786	.0297	"	"
Bromides: Methyl	CH_3Br	1.7331	.0205	0	Perkin
Ethyl	C_2H_5Br	1.4486	.0183	15	"
Carbon bisulphide	CS_2	1.26	.0420	18	Rayleigh
Chlorides: Carbon	CCl_4	1.60	.0321	15	Becquerel
Chloroform	$CHCl_3$	1.4823	.0164	20	Jahn
Ethyl	C_2H_5Cl	.9169	.0138	6	Perkin
Iodides: Methyl	CH_3I	2.2832	.0336	15	"
Ethyl	C_2H_5I	1.9417	.0296	"	"
Nitrates: Methyl	$CH_3O.NO_2$	1.2157	.0078	"	"
Ethyl	$C_2H_5O.NO_2$	1.1149	.0091	"	"
Paraffins: Pentane	C_5H_{12}	.6332	.0118	"	"
Hexane	C_6H_{14}	.6743	.0125	"	"
Toluene	C_7H_8	.8581	.0269	28	Schönrock
Water, = 0.2496μ	H_2O	..	.1042	..	See Meyer,
.275	..	..	.0776	..	Ann. der
.4046	..	..	.0293	..	Physik, 30,
.589	..	..	.0131	..	1909
1.000	..	..	.00410	..	..
1.300	..	..	.00264	..	..
Xylene	C_8H_{10}	.8746	.0263	27	Schönrock

TABLE 584.—Solutions of Acids and Salts in Water. Verdet's Constant for λ = 0.589μ

Chemical formula	Density grams per cm³	Verdet's constant in minutes	Temp. C	*	Chemical formula	Density grams per cm³	Verdet's constant in minutes	Temp. C	*
HBr	1.3775	0.0244	20°	P	Fe_2Cl_6	1.6933	−0.2026	15°	B
HCl	1.1573	.0204	"	"	"	1.5315	− .1140	"	"
"	1.0762	.0168	"	"	"	1.1681	− .0015	"	"
HI	1.9057	.0499	"	"	"	1.0864	.0081	"	"
"	1.1760	.0205	"	"	"	1.0232	.0122	"	"
HNO_3	1.3560	.0105	"	"	$HgCl_2$	1.0381	.0137	16	S
NH_3	.8918	.0153	15	"	$NiCl_2$	1.4685	.0270	15	B
NH_4Br	1.2805	.0226	"	"	"	1.2432	.0196	"	"
$BaBr_2$	1.5399	.0215	20	J	KCl	1.6000	.0163	"	"
$CdBr_2$	1.3291	.0192	"	"	$NaCl$	1.0418	.0144	"	J
$CaBr_2$	1.2491	.0189	"	"	$SrCl_2$	1.1921	.0162	"	"
KBr	1.1424	.0163	"	"	$SnCl_2$	1.3280	.0266	"	V
"	1.0876	.0151	"	"	$ZnCl_2$	1.2851	.0196	"	"
$NaBr$	1.1351	.0165	"	"	NH_4I	1.5948	.0396	"	P
"	1.0824	.0152	"	"	"	1.2341	.0235	"	"
K_2CO_3	1.1906	.0140	"	"	KI	1.6743	.0338	"	B
Na_2CO_3	1.1006	.0140	"	"	"	1.1705	.0182	"	"
NH_4Cl	1.0718	.0178	15	V	KNO_3	1.0634	.0130	20	J
$BaCl_2$	1.2897	.0168	20	J	$NaNO_3$	1.1112	.0131	"	"
$CdCl_2$	1.3179	.0185	"	"	$U_2O_3N_2O_5$	2.0267	.0053	"	B
"	1.1732	.0160	"	"	"	1.1963	.0115	"	"
$CaCl_2$	1.1504	.0165	"	"	$BaSo_4$	1.1788	.0134	"	J
"	1.0832	.0152	"	"	K_2SO_4	1.0475	.0133	"	"
$FeCl_2$	1.4331	.0025	15	B	Na_2SO_4	1.0661	.0135	"	"
"	1.1093	.0118	"	"					

* P, Perkin; J, Jahn; V, Verdet; B, Becquerel; S, Schönrock; see p. 476 for references.

MAGNETO-OPTIC ROTATION

TABLE 585.—Gases, Verdet's Constant

Substance.	Pressure.	Temp.	Verdet's constant in minutes.	Authority.
Atmospheric air	Atmospheric	Ordinary	6.83×10^{-6}	Becquerel.
Carbon dioxide	"	"	13.00 "	"
Carbon disulphide	74 cms.	70° C	23.49 "	Bichat.
Ethylene	Atmospheric	Ordinary	34.48 "	Becquerel.
Nitrogen	"	"	6.92 "	"
Nitrous oxide	"	"	16.90 "	"
Oxygen	"	"	6.28 "	"
Sulphur dioxide	"	"	31.39 "	"
" "	246 cms.	20° C	38.40 "	Bichat.

See also Siertsema, Ziting. Kon. Akad. Watt., Amsterdam, 7, 1899; 8, 1900.

Du Bois shows that in the case of substances like iron, nickel, and cobalt which have a variable magnetic susceptibility the expression in Verdet's equation, which is constant for substances of constant susceptibility, requires to be divided by the susceptibility to obtain a constant. For this expression he proposes the name "Kundt's constant." These experiments of Kundt and Du Bois show that it is not the difference of magnetic potential between the two ends of the medium, but the product of the length of the medium and the induction per unit area, which controls the amount of rotation of the beam.

TABLE 586.—Verdet's and Kundt's Constants

The following short table is quoted from Du Bois' paper. The quantities are stated in c. g. s. measure, circular measure (radians) being used in the expression of "Verdet's constant" and "Kundt's constant."

Name of substance.	Magnetic susceptibility.	Verdet's constant.		Wave-length of light in cms.	Kundt's constant.
		Number.	Authority.		
Cobalt	–	–	–	6.44×10^{-5}	3.99
Nickel	–	–	–	"	3.15
Iron	–	–	–	6.56 "	2.63
Oxygen: 1 atmo.	$+0.0126 \times 10^{-5}$	0.000179×10^{-5}	Becquerel.	5.89 "	0.014
Sulphur dioxide	−0.0751 "	0.302 "	"	"	−4.00
Water	−0.0694 "	0.377 "	Arons	"	−5.4
Nitric acid	−0.0633 "	0.356 "	Becquerel.	"	−5.6
Alcohol	−0.0566 "	0.330 "	De la Rive.	"	−5.8
Ether	−0.0541 "	0.315 "	"	"	−5.8
Arsenic chloride	−0.0876 "	1.222 "	Becquerel.	"	−14.9
Carbon disulphide	−0.0716 "	1.222 "	Rayleigh.	"	−17.1
Faraday's glass	−0.0982 "	1.738 "	Becquerel.	"	−17.7

TABLE 587.—Values of Kerr's Constant *

Du Bois has shown that the rotation of the major axis of vibration of radiations normally reflected from a magnet is algebraically equal to the normal component of magnetization multiplied into a constant K. He calls this constant K, Kerr's constant for the magnetized substance forming the magnet.

Color of light.	Spectrum line.	Wave-length in cms. $\times 10^6$	Kerr's constant in minutes per c. g. s. unit of magnetization.			
			Cobalt.	Nickel.	Iron.	Magnetite.
Red	Li α	67.7	—0.0208	—0.0173	—0.0154	+0.0096
Red	—	62.0	—0.0198	—0.0160	—0.0138	+0.0120
Yellow	D	58.9	—0.0193	—0.0154	—0.0130	+0.0133
Green	b	51.7	—0.0179	—0.0159	—0.0111	+0.0072
Blue	F	48.6	—0.0180	—0.0163	—0.0101	+0.0026
Violet	G	43.1	—0.0182	—0.0175	—0.0089	-

* H. E. J. G. Du Bois, "Phil. Mag." vol. 29.

TABLE 588.—Dispersion of Kerr Effect

Wave-length.	0.5μ	1.0μ	1.5μ	2.0μ	2.5μ
Steel . . .	—11′.	—16′.	—14′.	—11′.	—9′.0
Cobalt . . .	— 9.5	—11.5	— 9 5	—11.	—6.5
Nickel . . .	— 5.5	— 4.0	0	+1.75	+3.0

Field Intensity = 10,000 C. G. S. units. (Intensity of Magnetization = about 800 in steel, 700 to 800 in cobalt, about 400 in nickel). Ingersoll, Phil. Mag. 11, p. 41, 1906.

TABLE 589.—Dispersion of Kerr Effect

Mirror.	Field (C. G. S.)	.41μ	.44μ	.48μ	.52μ	.56μ	.60μ	.64μ	.66μ
Iron . .	21,500	—.25	—.26	—.28	—.31	—.36	—.42	—.44	—.45
Cobalt . .	20,000	—.36	—.35	—.34	—.35	—.35	—.35	—.35	—.36
Nickel . .	19,000	—.16	—.15	—.13	—.13	—.14	—.14	—.14	—.14
Steel . .	19,200	—.27	—.28	—.31	—.35	—.38	—.40	—.44	—.45
Invar . .	19,800	—.22	—.23	—.24	—.23	—.23	—.22	—.23	—.23
Magnetite	16,400	—.07	—.02	+.04	+.06	+.08	+.06	+.04	+.03

Foote, Phys. Rev. 34, p. 96, 1912.

See also Ingersoll, Phys. Rev. 35, p. 312, 1912, for "The Kerr Rotation for Transverse Magnetic Fields," and Snow, l. c. 2, p. 29, 1913, "Magneto-optical Parameters of Iron and Nickel."

RESISTANCE OF METALS. MAGNETIC EFFECTS

TABLE 590.—Temperature Variation of Resistance of Bismuth, Transverse Magnetic Field

H	Proportional Values of Resistance.								
	−192°	−135°	−100°	−37°	0°	+18°	+60°	+100°	+183°
0	0.40	0.60	0.70	0.88	1.00	1.08	1.25	1.42	1.79
2000	1.16	0.87	0.86	0.96	1.08	1.11	1.26	1.43	1.80
4000	2.32	1.35	1.20	1.10	1.18	1.21	1.31	1.46	1.82
6000	4.00	2.06	1.60	1.29	1.30	1.32	1.39	1.51	1.85
8000	5.90	2.88	2.00	1.50	1.43	1.42	1.46	1.57	1.87
10000	8.60	3.80	2.43	1.72	1.57	1.54	1.54	1.62	1.89
12000	10.8	4.76	2.93	1.94	1.71	1.67	1.62	1.67	1.92
14000	12.9	5.82	3.50	2.16	1.87	1.80	1.70	1.73	1.94
16000	15.2	6.95	4.11	2.38	2.02	1.93	1.79	1.80	1.96
18000	17.5	8.15	4.76	2.60	2.18	2.06	1.88	1.87	1.99
20000	19.8	9.50	5.40	2.81	2.33	2.20	1.97	1.95	2.03
25000	25.5	13.3	7.30	3.50	2.73	2.52	2.22	2.10	2.09
30000	30.7	18.2	9.8	4.20	3.17	2.86	2.46	2.28	2.17
35000	35.5	20.35	12.2	4.95	3.62	3.25	2.69	2.45	2.25

TABLE 591.—Increase of Resistance of Nickel due to a Transverse Magnetic Field, expressed as % of Resistance at 0° and H = 0

H	−190°	−75°	0°	+18°	+100°	+182°
0	+0	0	0	0	0	0
1000	+0.20	+0.23	+0.07	+0.07	+0.96	+0.04
2000	+0.17	+0.16	+0.03	+0.03	+0.72	−0.07
3000	0.00	−0.05	−0.34	−0.36	−0.14	−0.60
4000	−0.17	−0.15	−0.60	−0.72	−0.70	−1.15
6000	−0.19	−0.20	−0.70	−0.83	−1.02	−1.53
8000	−0.19	−0.23	−0.76	−0.90	−1.15	−1.66
10000	−0.18	−0.27	−0.82	−0.95	−1.23	−1.76
12000	−0.18	−0.30	−0.87	−1.00	−1.30	−1.85
14000	−0.18	−0.32	−0.91	−1.04	−1.37	−1.95
16000	−0.17	−0.35	−0.94	−1.09	−1.44	−2.05
18000	−0.17	−0.38	−0.98	−1.13	−1.51	−2.15
20000	−0.16	−0.41	−1.03	−1.17	−1.59	−2.25
25000	−0.14	−0.49	−1.12	−1.29	−1.76	−2.50
30000	−0.12	−0.56	−1.22	−1.40	−1.95	−2.73
35000	−0.10	−0.63	−1.32	−1.50	−2.13	−2.98

F. C. Blake, Ann. der Physik, 28, p. 449; 1909.

TABLE 592.—Change of Resistance of Various Metals in a Transverse Magnetic Field. Room Temperature

Metal.	Field Strength in Gausses.	Per cent Increase.	Authority.
Nickel	10000	−1.2	Williams, Phil. Mag. 9, 1905.
"	"	−1.4	Barlow, Pr. Roy. Soc. 71, 1903.
"	6000	−1.0	Dagostino, Atti Ac. Linc. 17, 1908.
"	10000	−1.4	Grummach, Ann. der Phys. 22, 1906.
Cobalt	"	−0.53	"
Cadmium	"	+0.03	"
Zinc	"	+0.01	"
Copper	"	+0.004	"
Silver	"	+0.004	"
Gold	"	+0.003	"
Tin	"	+0.002	"
Palladium	"	+0.001	"
Platinum	"	+0.0005	"
Lead	"	+0.0004	"
Tantalum	"	+0.0003	"
Magnesium	6000	+0.01	Dagostino, *l. c.*
Manganin	"	+0.01	"
Tellurium	?	+0.02 to 0.34	Goldhammer, Wied Ann. 31, 1887.
Antimony	?	+0.02 to 0.16	"
Iron	Different specimens show very diverse results, usually an increase in weak fields, a decrease in strong.		Grummach, *l. c.* Barlow, *l. c.* Williams, *l. c.*
Nickel steel	Alloys behave similarly to iron.		Williams, *l. c.*

TABLE 593.—Transverse Galvanomagnetic and Thermomagnetic Effects

Effects are considered positive when, the magnetic field being directed away from the observer, and the primary current of heat or electricity directed from left to right, the upper edge of the specimen has the higher potential or higher temperature.

E = difference of potential produced; T = difference of temperature produced; I = primary current; $\frac{dt}{dx}$ = primary temperature gradient; B = breadth, and D = thickness, of specimen H = intensity of field. C. G. S. units.

Hall effect (Galvanomagnetic difference of Potential), $E = R\frac{HI}{D}$

Ettingshausen effect (" " " Temperature), $T = P\frac{HI}{D}$

Nernst effect (Thermomagnetic " " Potential), $E = QHB\frac{dt}{dx}$

Leduc effect (" " " Temperature), $T = SHB\frac{dt}{dx}$

Substance.	Values of R.	$P \times 10^6$.	$Q \times 10^6$.	$S \times 10^8$.
Tellurium	+400 to 800	+200	+360000	+400
Antimony	+ 0.9 " 0.22	+2	+9000 to 18000	+200
Steel	+.012 " 0.033	—0.07	—700 " 1700	+69
Heusler alloy	+.010 " 0.026	–	+1600 " 7000	
Iron	+.007 " 0.011	—0.06	—1000 " 1500	+39
Cobalt	+.0016 " 0.0046	+0.01	+1800 " 2240	+13
Zinc	–	–	—54 " 240	+13
Cadmium	+.00055			
Iridium	+.00040	–	up to —5.0	+5
Lead	+.00009	–	—5.0 (?)	
Tin	—.00003	–	—4.0 (?)	
Platinum	—.0002	–	–	—2
Copper	—.00052	–	—90 to 270	—18
German silver	—.00054			
Gold	—.00057 to .00071			
Constantine	—.0009			
Manganese	—.00093			
Palladium	—.0007 to .0012	–	+50 to 130	—3
Silver	—.0008 " .0015	–	—46 " 430	—41
Sodium	—.0023			
Magnesium	—.00094 to .0035			
Aluminum	—.00036 " .0037			
Nickel	—.0045 " .024	+0.04 to 0.19	+2000 " 9000	—45
Carbon	—.017	+5.	+100	
Bismuth	up to 16.	+3 to 40	+ up to 132000	—200

TABLE 594.—Variation of Hall Constant with the Temperature

Bismuth.[1]						Antimony[2]				
H	—182°	—90°	—23°	+11.5°	+100°	H	—186°	—79°	+21.5°	+58°
1000	62.2	28.0	17.0	13.3	7.28	1750	0.263	0.249	0.217	
2000	55.0	25.0	16.0	12.7	7.17	3960	0.252	0.243	0.211	
3000	49.7	22.9	15.1	12.1	7.06	6160	0.245	02.35	0.209	0.203
4000	45.8	21.5	14.3	11.5	6.95					
5000	42.6	20.2	13.6	11.0	6.84					
6000	40.1	18.9	12.9	10.6	6.72					

Bismuth.[3]									
H	+14.5°	+104°	125°	189°	212°	239°	259°	269°	270°
890	5.28	2.57	2.12	1.42	1.24	1.11	0.97	0.83	0.77*

[1] Barlow, Ann. der Phys. 12, 1903. [2] Everdingen, Comm. Phys. Lab. Leiden, 58.
[3] Traubenberg, Ann. der Phys. 17, 1905. * Melting-point.

Both tables taken from Jahn, Jahrbuch der Radioactivität und Electronik. 5, p. 166; 1908, who has collected data of all observers and gives extensive bibliography.

Table 595

INTERNATIONAL ATOMIC WEIGHTS, ATOMIC NUMBERS AND VALENCIES

Quoted from the 1st Report of the Committee on Atomic Weights of the International Union of Chemistry (Journ. Amer. Chem. Soc., 3, 1637, 1931).

Element	Symbol and atomic number	Relative atomic weight oxygen = 16	Valencies	Element	Symbol and atomic number	Relative atomic weight oxygen = 16	Valencies
Aluminum	Al 13	26.97	3	Molybdenum	Mo 42	96.0	4, 6
Antimony	Sb 51	121.76	3, 5	Neodymium	Nd 60	144.27	3
Argon	A 18	39.944	0	Neon	Ne 10	20.183	0
Arsenic	As 33	74.93	3, 5	Nickel	Ni 28	58.69	2, 3
Barium	Ba 56	137.36	2	Nitrogen	N 7	14.008	3, 5
Beryllium	Be 4	9.02	2	Osmium	Os 76	190.8	6, 8
Bismuth	Bi 83	209.00	3, 5	Oxygen	O 8	16.0000	2
Boron	B 5	10.82	3	Palladium	Pd 46	106.7	2, 4
Bromine	Br 35	79.916	1	Phosphorus	P 15	31.02	3, 5
Cadmium	Cd 48	112.41	2	Platinum	Pt 78	195.23	2, 4
Calcium	Ca 20	40.08	2	Potassium	K 19	39.10	1
Carbon	C 6	12.000	4	Praseodymium	Pr 59	140.92	3
Cerium	Ce 58	140.13	3, 4	Radium	Ra 88	225.97	2
Cesium	Cs 55	132.81	1	Radon	Rn 86	222	0
Chlorine	Cl 17	35.457	1	Rhenium	Re 75	186.31	..
Chromium	Cr 24	52.01	2, 3, 6	Rhodium	Rh 45	102.91	3
Cobalt	Co 27	58.94	2, 3	Rubidium	Rb 37	85.44	1
Columbium	Cb 41	93.3	5	Ruthenium	Ru 44	101.7	6, 8
Copper	Cu 29	63.57	1, 2	Samarium	Sm 62	150.43	3
Dysprosium	Dy 66	162.46	3	Scandium	Sc 21	45.10	3
Erbium	Er 68	167.64	3	Selenium	Se 34	79.2	2, 4, 6
Europium	Eu 63	152.0	3	Silicon	Si 14	28.06	4
Fluorine	F 9	19.00	1	Silver	Ag 47	107.880	1
Gadolinium	Gd 64	157.3	3	Sodium	Na 11	22.997	1
Gallium	Ga 31	69.72	3	Strontium	Sr 38	87.63	2
Germanium	Ge 32	72.60	4	Sulphur	S 16	32.06	2, 4, 6
Gold	Au 79	197.2	1, 3	Tantalum	Ta 73	181.4	5
Hafnium	Hf 72	178.6	..	Tellurium	Te 52	127.5	2, 4, 6
Helium	He 2	4.002	0	Terbium	Tb 65	159.2	3
Holmium	Ho 67	163.5	3	Thallium	Tl 81	204.39	1, 3
Hydrogen	H 1	1.0078	1	Thorium	Th 90	232.12	4
Indium	In 49	114.8	3	Thulium	Tm 69	169.4	3
Iodine	I 53	126.932	1	Tin	Sn 50	118.70	2, 4
Iridium	Ir 77	193.1	4	Titanium	Ti 22	47.90	4
Iron	Fe 26	55.84	2, 3	Tungsten	W 74	184.0	6
Krypton	Kr 36	82.9	0	Uranium	U 92	238.14	4, 6
Lanthanum	La 57	138.90	3	Vanadium	V 23	50.95	3, 5
Lead	Pb 82	207.22	2, 4	Xenon	Xe 54	130.2	0
Lithium	Li 3	6.940	1	Ytterbium	Yb 70	173.5	3
Lutecium	Lu 71	175.0	3	Yttrium	Y 39	88.92	3
Magnesium	Mg 12	24.32	2	Zinc	Zn 30	65.38	2
Manganese	Mn 25	54.93	2, 3, 7	Zirconium	Zr 40	91.22	4
Mercury	Hg 80	200.61	1, 2				

TABLE 596

ISOTOPES. PACKING FRACTIONS

(See Table 851)

This table contains several sets of values. Those followed directly by figures in parentheses, e.g., Sn, 118.72 (−7.13 ± 2), taken from Aston, Proc. Roy. Soc., 115A, 487, 1927, give first the atomic mass referred to oxygen (O_{16} + O_{17}) determined by the mass spectroscope and often of greater probable accuracy than the corresponding atomic weight determination (see Birge, p. 81 ff.). The figures following in parentheses are "packing fractions". The protons and electrons are so closely packed that their electromagnetic fields interfere and a certain fraction of the combined mass is destroyed. The mass destroyed corresponds to energy released. The greater this is the more tightly are the charges cemented and the more stable the nucleus. The "fraction" measures the divergence from the "whole number" rule divided by the mass number, expressed in parts per 10,000. The numbers in braces are ordinary atomic weights from page 483. Numbers in brackets are % abundance. The other numbers are the nearest whole numbers to the mass of the corresponding isotope. Aston, Philos. Mag., 49, 1199, 1925. See page 486 for the radioactive isotopes.

H	1	2	1.00778(77.8 ± 1.5) Abundance of 2, 1/800
He	2	1	4.00216(5.4 ± 1)
Li	3	2	6.012(20.0 ± 3), 7.012(17.0 ± 3)
Be	4	1	{9.02} (Aston)
B	5	2	10.0135(13.5 ± 1.5), 11.0110(10.0 ± 1.5)
C	6	2	12.0036(3.0 ± 1), 13 (Birge, 1929) [Relative abundance, 400–1]
N	7	1	14.008(5.7 ± 2), 15 (Naudé, 1929) [Relative abundance, 700–1]
O	8	2	16.0000, 17, 18, (Giauque, Johnston, 1929)[Abundance O_{16}/O_{17} = 8600, O_{16}/O_{18} = 1100]
F	9	1	19.000(0.0 ± 1)
Ne	10	2	20.0004(0.2 ± 1), 22.0048(2.2?)
Na	11	1	{22.997} (Aston)
Mg	12	3	24, 25, 26 (Dempster)
Al	13	1	{26.97} (Aston)
Si	14	3	28, 29, 30 (Aston)
P	15	1	30.9825(− 5.6 ± 1.5)
S	16	3	32, 97% of whole; 34, 33 (Aston)
Cl	17	2	34.983(−4.8 ± 1.5), 36.980(−5.0 ± 1.5)
A	18	2	39.971(−7.2 ± 1), 35.976(−6.6 ± 5), 1% of whole
K	19	2	39, 41 (Aston)
Ca	20	2?	40, 44? (Dempster)
Sc	21	1	{45.10} (Aston)
Ti	22	1	{47.90} (Aston)
V	23	1	{50.96} (Aston)
Cr	24	4	{52.011} 52(− 10)[82], 53[10], 50[5], 54[3], Aston, 1930
Mn	25	1	{54.93} (Aston)
Fe	26	2?	56, 54? (Aston)
Ni	28	2	58, 60 (Aston)
Zn	30	4	{65.380} (− 9.9), 64[48], 66[26], 68[17], 65[2], 67[5], 69[1], 70[0.4]
As	33	1	74.934(− 8.8 ± 1.5)
Se	34	6	80, 78, 76, 82, 77, 74 (Aston)
Br	35	2	78.929(− 9.0 ± 1.5), 80.926(− 8.6 ± 1.5)
Kr	36	6	83.928(− 8.5 ± 2)[57], 85.929(− 8.2 ± 1.5)[17], 81.927(− 8.8 ± 1.5)[12] 82.927(− 8.17 ± 1.5)[12], 79.926(− 9.4 ± 2)[2], 77.926(− 9.4 ± 2)[.4]
Rb	37	2	85, 87 (Aston)
Sr	38	2	88, 86 (Aston)
Yt	39	1	{88.92} (Aston)
Zr	40	3	{91.22} (Aston)
Mo	42	7	95.97(− 5.5), 98(− 5.5)[23], 96[18], 95[15], 92[14], 94[10], 100(− 5.5)[10], 97[10]
Ru	44	7	102[30], 101[22], 104[17], 100[14], 99[12], 96[5], 98?, (Aston, 1931)
In	49	1	{114.8} (Aston)
Sn	50	11	118.72(− 7.3 ± 2), 120[27.0], 118[21], 116[14.1], 124[6.2], 119[11.0], 117[9.8], 122[5.0], 121[3.0], 112[1.1], 114[.7], 115[0.4] (Probably all the same packing fraction.)
Sb	51	2	121, 123 (Aston)
Te	52	3	128, 130, 126 (Aston)
I	53	1	126.932(− 5.13 ± 2)
Xe	54	9	131.27(− 5.3), 129[27.1], 132[26.4], 131[20.7], 134[10.3], 136[8.8], 130[4.2], 128]2.3] 126[.1], 124[.1] (Probably all the same packing fraction.)
Cs	55	1	{132.81} (Aston)
Pr	59	1	{140.92} (Aston)
Nd	60	3	142, 144, 146, (145) (Aston)
Os	76	6	190.31(− 1.0 ± 2.0), 192[42.6], 190[25.1], 189[17.3], 188[13.5], 186[1.0], 187[0.6] (Aston, 1931)
Hg	80	6	200.62(+ .08), 202[29.27], 200[23.77], 199[16.4], 198[10], 201[13.7], 204[6.8], 196[.1] (All same packing fraction.)
Tl	81	8	207, 205, 211, 203, 201, 209, 213, 215, Goslin, Allison
U	92	8	238, 239, 240, 234, 237, 235, 233, 236, Goslin, Allison

Corrections (Nature 192, 477, Mar. 26, 1932.
Kr 83.7, Xe 131.3.

Calculation of atomic weights from mass spectra leads to the following: (O = 16): Ratio isotopes O16: O18:O17::630:1:0.2.

Li 6.923, Cs 132.91, B 10.806, Ge 72.65, Se 78.96, Te 128.03, W 183.96, Br 79.916, Re 186.22, Ru 101.1, Os 190.31.

For isotopes of Pb (201 to 216), Bi (205 to 217, 219), Ra (226, 228, 230, 232), Th (229 to 236); Bishop, Lawrenz, Dollins, Allison, Goslin, Phys. Rev. 43, 1933.

TABLE 597.—Periodic System of the Elements

O	I	II	III	IV	V	VI	VII	
—	R_2O	RO	R_2O_3	RO_2	R_2O_5	RO_3	R_2O_7	RO_4 ☞ Oxides.
—	—	—	—	RH_4	RH_3	RH	RH	— ☞ Hydrides.
He 4	Li 7	Gl 9	B 11	C 12	N 14	O 16	F 19	— —
Ne 20	Na 23	Mg 24	Al 27	Si 28	P 31	S 32	Cl 35	— —
A 40	K 39	Ca 40	Sc 44	Ti 48	V 51	Cr 52	Mn 55	Fe 56 Ni 59 Co 59
— —	Cu 64	Zn 65	Ga 70	Ge 72	As 75	Se 79	Br 80	— —
Kr 82	Rb 85	Sr 88	Yt 89	Zr 91	Cb 94	Mo 96	— —	Ru 102 Rh 103 Pd 107
— —	Ag 108	Cd 112	In 115	Sn 119	Sb 120	Te 128	I 127	— —
X 128	Cs 133	Ba 137	La 139	Ce 140	Pr 141	Nd 144	— —	— —
— —	Sa 150	Eu 152	Gd 157	Tb 159	Ds 162	Er 168	— —	— —
— —	Tm 168	Yb 174	Lu 175	— —	Ta 181	W 184	— —	Os 191 Ir 193 Pt 195
— —	Au 197	Hg 201	Tl 204	Pb 207	Bi 208	Po 210	— —	— —
Em (222)	— —	Ra 226	Ac (227)	Th 232	UrX_2 234	U 238	— —	— —

TABLE 598.—Atomic Numbers

1 Hydrogen
2 Helium
3 Lithium
4 Beryllium †
5 Boron
6 Carbon
7 Nitrogen
8 Oxygen
9 Fluorine
10 Neon
11 Sodium
12 Magnesium
13 Aluminum
14 Silicon
15 Phosphorus
16 Sulphur
17 Chlorine
18 Argon
19 Potassium
20 Calcium
21 Scandium
22 Titanium
23 Vanadium
24 Chromium
25 Manganese
26 Iron
27 Cobalt
28 Nickel
29 Copper
30 Zinc
31 Gallium
32 Germanium
33 Arsenic
34 Selenium
35 Bromine
36 Krypton
37 Rubidium
38 Strontium
39 Yttrium
40 Zirconium
41 Niobium ‡
42 Molybdenum
43 Masurium
44 Ruthenium
45 Rhodium
46 Palladium
47 Silver
48 Cadmium
49 Indium
50 Tin
51 Antimony
52 Tellurium
53 Iodine
54 Xenon
55 Cesium
56 Barium
57 Lanthanum
58 Cerium
59 Praseodymium
60 Neodymium
61 Illinium
62 Samarium
63 Europium
64 Gadolinium
65 Terbium
66 Dysprosium
67 Holmium
68 Erbium
69 Thulium
70 Ytterbium
71 Lutecium
72 Hafnium
73 Tantalum
74 Tungsten
75 Rhenium *
76 Osmium
77 Iridium
78 Platinum
79 Gold
80 Mercury
81 Thalium
82 Lead
83 Bismuth
84 Polonium
85 Alabamine
86 Radon
87 Virginium
88 Radium
89 Actinium
90 Thorium
91 Protactinium
92 Uranium

* Bohemium

† Glucinium.

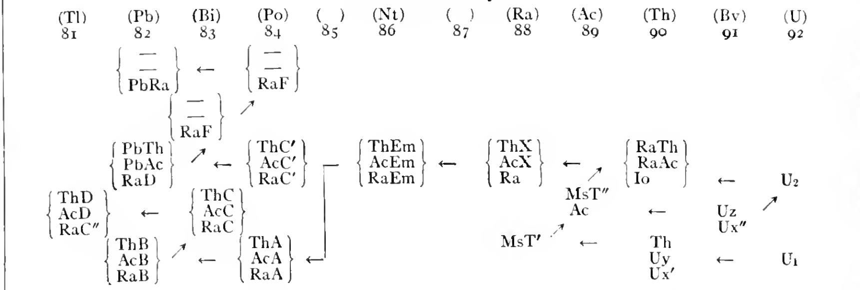
‡ Columbium.

TABLE 599

PERIODIC SYSTEM AND THE RADIOACTIVE ISOTOPES*

	4	5A	6A	7A	O	1A	2A	3A	4	
		Non-metals.			Inert-gases.	Light-metals.				
Vb	82 Pb	83 Bi	84 Po	85 —	86 Nt	87 —	88 Ra	89 Ac	90 Th	VI
IVb	50 Sn	51 Sb	52 Te	53 I	54 Xe	55 Cs	56 Ba	57 La	58 Ce	Va
IIIb	32 Ge	33 As	34 Se	35 Br	36 Kr	37 Rb	38 Sr	39 Y	40 Zr	IVa
IIb	14 Si	15 P	16 S	17 Cl	18 Ar	19 K	20 Ca	21 Sc	22 Ti	IIIa
Ib	6 C	7 N	8 O	9 F	10 Ne	11 Na	12 Mg	13 Al	14 Si	IIa
	— —		1 H		2 He	3 Li	4 Be	5 B	6 C	Ia
		Heavy metals.								
III′	22 Ti	23 V	24 Cr	25 Mn	26 Fe, 27 Co, 28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	III′
IV′	40 Zr	41 Cb	42 Mo	43 —	44 Ru, 45 Rh, 46 Pd	47 Ag	48 Cd	49 In	50 Sn	IV′
V″	58 Ce	59 Pr, 60 Nd	61 —, 62 Sa	63 Eu	64 Gd, 65 Tb, 66 Dy, 67 Ho	68 Er	69 Ad	70 Cp, 71 Yb	72 Lu	V″
V′	72 Lu	73 Ta	74 W	75 —	76 Os, 77 Ir, 78 Pt	79 Au	80 Hg	81 Tl	82 Pb	V′
VI	90 Th	91 Bv	92 U	— —						VI
	4	5B	6B	7B		1B	2B	3B	4	

Radioactive isotopes.



← Indicates the loss of an alpha particle (producing He); the element becomes more electro-positive and the atomic weight decreases by 4, position changing 2 columns to the left.

↗ Indicates beta radiation (loss of electron); the element becomes more electro-negative, atomic weight remains the same, position changes one column to the right and up.

Isotopes of an element have the same valency and the same chemical properties (solubility, reactivity, etc.), although their atomic weights may differ. The isotopes of Bi are, e.g., RaE, ThC, AcC, RaC.

In the *upper* half of the table are the elements possessing high electro potential, simple spectra, colorless ions. The properties are analogous in the vertical direction (groups). In the *lower* half are the elements with low electro-potential, complex spectra, colored ions and tending to form complex double salts, the general properties of the elements being more pronounced in the horizontal direction (periods).

On the *left* side of the table are the electro-negative elements, those of the upper half forming strong acids, those of the lower half weak oxyacids.

On the *right* side of the table are the electro-positive elements, forming bases, oxysalts, sulfides, etc.

The *center* of the lower half is occupied by the amphoteric elements forming weak acids and bases, many complex compounds and double salts, many insoluble and mostly colored compounds.

A very striking point, however, is, as already mentioned, that the *similarity among the elements* in the upper half is in the vertical direction, and in the lower half in the horizontal direction. This justifies the use of the expressions group-relation and period-relation.

* Table adapted from Hackh, J. Am. Chem. Soc. 40, 1023, 1918, Phys. Rev. 13, 169, 1919.

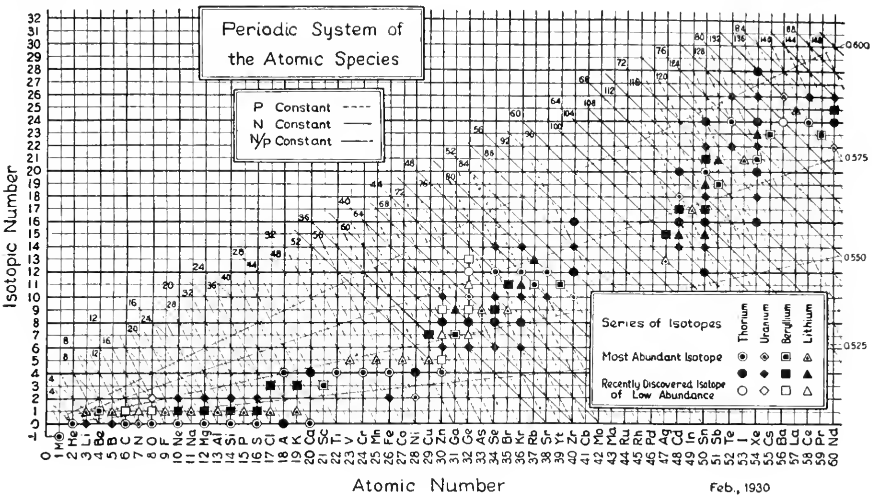
Note: See Radioactive Families with isotopes, Edna Bishop. The Physical Review, 43, 38, 1933.

Table 600
ATOMIC STRUCTURE

(Harkins, Science, 70, 433, 463, 1929.)

If weight of proton (p) + electron (e) = 1, atomic wt. = no. of protons + electrons in atom. $(pe)_w$ = composition of complete atom, atomic weight (w). P, no. of protons in atom, = W. N = total number electrons in nucleus; $P - N = Z$ = atomic number. $2N - P$ = isotopic number; electronic number = no. electrons.

The structure of the loosely bound nonnuclear electrons decides various chemical and physical properties. The tightly bound nuclear atoms should produce periodic properties. Abundance of atomic species reveals nuclear stability (possibility of other factors). High stability shown by abundance of even electronic numbers. Species of odd electronic number are so rare that only four have been discovered. There is high stability for isotopic numbers divisible by 4, a secondary stability when by 2. When N and P even, Z odd, earth's crust 87.4%; meteorites, 95.4; when N even, P, Z odd, 10.8, 2.1; Z even, P, N odd, 1.8, 2.5; P even, N, Z odd, 0.0007, 0.0. Lower left-hand rectangle of lower figure constitutes 99.9% of all known material.



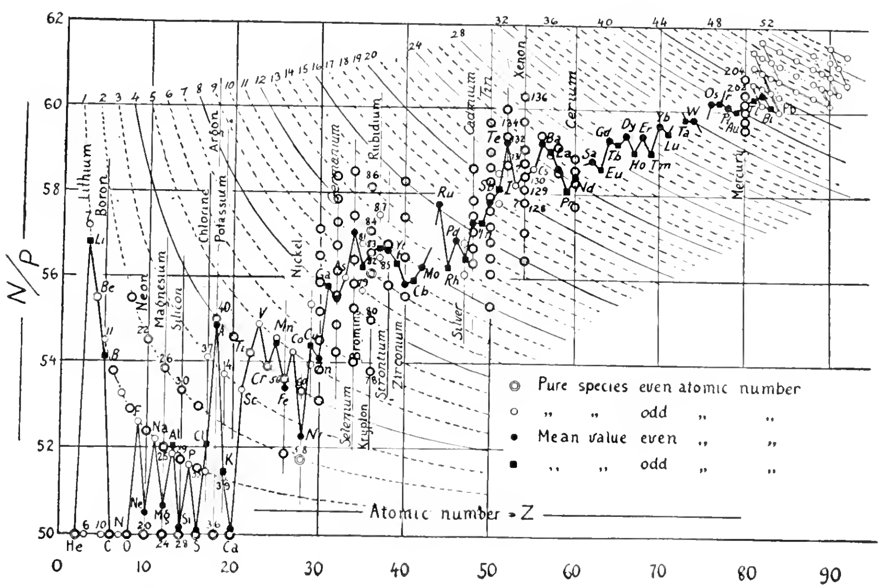


TABLE 601

ELECTRON CONFIGURATIONS IN NORMAL ATOM

Individual electrons in an atom may be designated by two quantum numbers, "azimuthal" and "total". The first is expressed by s, p, d, etc.; the last numerically in specific cases, by n in general.

Designation of quantum numbers:

Azimuth quantum: literal, s; number, 0; Bohr, k, 1; The total quantum number is equal to or greater than $l + 1$, i.e., 1, 2, 3, — for s electrons, 2, 3, 4,— for p electrons, etc.

literal	number	Bohr, k
s	0	1
p	1	2
d	2	3
f	3	4
g	4	5
h etc.	5	6

An electron is called, e.g., a 6p electron, 6 for the total quantum number, p implying an l value of 1. Note that 4p, 5s, 3d, etc., electrons are equivalent to Bohr's 4_2, 5_1, 3_3 electrons. The number of electrons for a given type in an atom may be expressed by an exponent, e.g., $3d^5$. For more detailed connection between configurations and spectroscopic terms see Hund's book. The lower-case letters n, l, s, j, m should be used for the quantum numbers of an electron, and the capitals L, S, J, M for the quantum numbers of a term (or level) of an atom, ionized or neutral. A specification of atomic structure would include all the inner electrons, e.g., for Fe in its normal state $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$. For short only those electrons "outside" an inert gas shell need be considered. A complete np^6 group, and all the groups which are normally completed earlier in the periodic table, can be neglected. Thus the notation for the normal state of Fe becomes $3d^6 4s^2$.

Examples of the notation for a level and the configuration from which it arises is $3d^6\,4s^2\ {}^5D_4$, the normal state of the iron atom; $2s^2\,2p^3\ {}^4S^\circ_{1\,1/2}$, the low level of O II. The total quantum numbers may be omitted when they are the lowest which the particular sort of electron can have if not belonging to already completed shells. For example, 4s, 4p, 3d, 4f in spectra from K I to Zn I and Ca II to Ga II, etc., are the s, p, d, and f electrons of lowest quantum numbers not belonging to completed groups. The $3p^6$ group is completed and the $3s^2$ and all the groups of smaller n have been previously completed, leaving 4s, 4p, 3d, 4f still to be added. These last can therefore be represented by s, p, d and f.

The normal state of Fe I would thus be designated as $d^6 s^2\ {}^5D_4$, that of O II as $s^2 p^3\ {}^4S^\circ_{1\,1/2}$. For Ge I, in which the electron groups $3d^{10}$ and $4s^2$ may be regarded as completed, the electrons to be represented by the letters alone would be the 5s, 4p, 4d, and 4f electrons; and so on.

Odd terms arise when the sum of the l values for all electrons is odd, even terms from configurations for which the l sum is even. Since the l sum for completed groups is always even, only outer uncompleted groups need be considered. Even (odd) terms are those in which the number of p and f electrons together is even (odd). In the parts of the periodic table where s and d groups are being completed the lowest terms of all the atoms are even. Where p groups are being completed (and also in the rare earth f-group) the lowest terms are alternately odd and even. Except in the rare earth group the only spectra for which the normal state corresponds to an odd term are B I, N I, F I and C II, O II, Ne II etc. and the homologous spectra in later periods.

Permitted transitions are those in which the l of one electron changes by one unit, (and the l of another electron by 0 or 2 units, if two electrons change) so that all such transitions are between even and odd terms.

Electron Configurations[1]

Element	K	L		M			N				O			Normal term	Atomic No.
	1,0	2,0	2,1	3,0	3,1	3,2	4,0	4,1	4,2	4,3	5,0	5,1	5,2		
	1s	2s	2p	3s	3p	3d	4s	4p	4d	4f	5s	5p	5d		
H	1	..	..	..	..	..	..	..	..	..	..	..	..	$^2S_{1/2}$	1
He	2	..	..	..	..	..	..	..	..	..	..	..	..	$^1S_0$	2
Li	2	1	..	..	..	..	..	..	..	..	..	..	..	$^2S_{1/2}$	3
Be	2	2	..	..	..	..	..	..	..	..	..	..	..	$^1S_0$	4
B	2	2	1	..	..	..	..	..	..	..	..	..	..	$^2P_{1/2}$	5
C	2	2	2	..	..	..	..	..	..	..	..	..	..	$^3P_0$	6
N	2	2	3	..	..	..	..	..	..	..	..	..	..	$^4S_{3/2}$	7
O	2	2	4	..	..	..	..	..	..	..	..	..	..	$^3P_2$	8
F	2	2	5	..	..	..	..	..	..	..	..	..	..	$^2P_{3/2}$	9
Ne	2	2	6	..	..	..	..	..	..	..	..	..	..	$^1S_0$	10
Na	Same as for neon			1	..	..	..	..	..	..	..	..	..	$^2S_{1/2}$	11
Mg	"			2	..	..	..	..	..	..	..	..	..	$^1S_0$	12
Al	"			2	1	..	..	..	..	..	..	..	..	$^2P_{1/2}$	13
Si	"			2	2	..	..	..	..	..	..	..	..	$^3P_0$	14
P	"			2	3	..	..	..	..	..	..	..	..	$^4S_{3/2}$	15
S	"			2	4	..	..	..	..	..	..	..	..	$^3P_2$	16
Cl	"			2	5	..	..	..	..	..	..	..	..	$^2P_{3/2}$	17
A	"			2	6	..	..	..	..	..	..	..	..	$^1S_0$	18

[1] Based by permission upon table by Ruark and Urey. Atoms, molecules, and quanta. 1930.

ELECTRON CONFIGURATIONS IN NORMAL ATOM

Element	K L	M			N				O			P		Normal term	Atomic No.
		3,0	3,1	3,2	4,0	4,1	4,2	4,3	5,0	5,1	5,2	6,0	6,1		
		3s	3p	3d	4s	4p	4d	4f	5s	5p	5d	6s	6p		
K	Same as for Argon			..	1	..	..	..	..	..	..	..	..	$^2S_{1/2}$	19
Ca	"			..	2	..	..	..	..	..	..	..	..	$^1S_0$	20
Sc	"			1	2	..	..	..	..	..	..	..	..	$^2D_{3/2}$	21
Ti	"			2	2	..	..	..	..	..	..	..	..	$^3F_2$	22
V	"			3	2	..	..	..	..	..	..	..	..	$^4F_{3/2}$	23
Cr	"			5	1	..	..	..	..	..	..	..	..	$^7S_3$	24
Mn	"			5	2	..	..	..	..	..	..	..	..	$^6S_{5/2}$	25
Fe	"			6	2	..	..	..	..	..	..	..	..	$^5D_4$	26
Co	"			7	2	..	..	..	..	..	..	..	..	$^4F_{9/2}$	27
Ni	"			8	2	..	..	..	..	..	..	..	..	$^3F_4$	28
Cu	"			10	1	..	..	..	..	..	..	..	..	$^2S_{1/2}$	29
Zn	"			10	2	..	..	..	..	..	..	..	..	$^1S_0$	30
Ga	"			10	2	1	..	..	..	..	..	..	..	$^2P_{1/2}$	31
Ge	"			10	2	2	..	..	..	..	..	..	..	$^3P_0$	32
As	"			10	2	3	..	..	..	..	..	..	..	$^4S_{3/2}$	33
Se	"			10	2	4	..	..	..	..	..	..	..	$^3P_2$	34
Br	"			10	2	5	..	..	..	..	..	..	..	$^2P_{3/2}$	35
Kr	"			10	2	6	..	..	..	..	..	..	..	$^1S_0$	36
Rb	Same as for krypton						..	..	1	..	..	..	..	$^2S_{1/2}$	37
Sr	"						..	..	2	..	..	..	..	$^1S_0$	38
Y	"						1	..	2	..	..	..	..	$^2D_{3/2}$	39
Zr	"						2	..	2	..	..	..	..	$^3F_2$	40
Cb	"						4	..	1	..	..	..	..	$^6D_{1/2}$	41
Mo	"						5	..	1	..	..	..	..	$^7S_3$	42
...	"						(6)	..	(1)	..	..	..	..	($^6D_{9/2}$)	43
Ru	"						7	..	1	..	..	..	..	$^5F_5$	44
Rh	"						8	..	1	..	..	..	..	$^4F_{9/2}$	45
Pd	"						10	..	..	..	..	..	..	$^1S_0$	46
Ag	Same as for palladium							..	1	..	..	..	..	$^2S_{1/2}$	47
Cd	"							..	2	..	..	..	..	$^1S_0$	48
In	"							..	2	1	..	..	..	$^2P_{1/2}$	49
Sn	"							..	2	2	..	..	..	$^3P_0$	50
Sb	"							..	2	3	..	..	..	$^4S_{3/2}$	51
Te	"							..	2	4	..	..	..	$^3P_2$	52
I	"							..	2	5	..	..	..	$^2P_{3/2}$	53
Xe	"							..	2	6	..	..	..	$^1S_0$	54

TABLE 601 (*concluded*)

ELECTRON CONFIGURATIONS IN NORMAL ATOM

Element	K L M	N 4,0 4s	N 4,1 4p	N 4,2 4d	N 4,3 4f	O 5,0 5s	O 5,1 5p	O 5,2 5d	O 5,3 5f	P 6,0 6s	P 6,1 6p	P 6,2 6d	Q 7,0 7s	Normal term	Atomic No.
Cs	Xenon configuration.				..	Shell		..	..	1	..	..	..	$^{2}S_{1/2}$	55
Ba	Shells 1s to 4d con-				..	5s		..	..	2	..	..	..	$^{1}S_{0}$	56
La	tain 46 electrons.				..	to		1	..	2	..	..	..	$^{2}D_{3/2}$	57
Ce	"				1	5p		1	..	2	..	..	..	$^{3}H_{4}$	58
Pr	"				2	con-		1	..	2	..	..	..	$^{4}K_{11/2}$	59
Nd	"				3	tain		1	..	2	..	..	..	$^{5}L_{6}$	60
Il	"				4	8		1	..	2	..	..	..	$^{6}L_{9/2}$	61
Sa	"				5	elec-		1	..	2	..	..	..	$^{7}K_{4}$	62
Eu	"				6	trons		1	..	2	..	..	..	$^{8}H_{3/2}$	63
Gd	"				7			1	..	2	..	..	..	$^{9}D_{2}$	64
Tb	"				8			1	..	2	..	..	..	$^{8}H_{17/2}$	65
Dy	"				9			1	..	2	..	..	..	$^{7}K_{10}$	66
Ho	"				10			1	..	2	..	..	..	$^{6}L_{19/2}$	67
Er	"				11			1	..	2	..	..	..	$^{5}L_{10}$	68
Tu	"				12			1	..	2	..	..	..	$^{4}K_{17/2}$	69
Yb	"				13			1	..	2	..	..	..	$^{3}H_{6}$	70
Lu	"				14			1	..	2	..	..	..	$^{2}D_{3/2}$	71
Hf	Shells 1s to 5p contain 68 electrons							2	..	2	..	..	..	$^{3}F_{2}$	72
Ta	"							3	..	2	..	..	..	$^{4}F_{3/2}$	73
W	"							4	..	2	..	..	..	$^{5}D_{0}$	74
Re	"							5	..	2	..	..	..	$^{6}S_{5/2}$	75
	"							6	..	1	..	..	..	$^{6}D_{9/2}$	..
Os	"							6	..	2	..	..	..	$^{5}D_{4}$	76
	"							7	..	1	..	..	..	$^{5}F_{5}$	..
Ir	"							7	..	2	..	..	..	$^{4}F_{9/2}$	77
	"							8	..	1	..	..	..	$^{4}F_{9/2}$	..
Pt	"							9	..	1	..	..	..	$^{3}D_{3}$	78
Au	Shells 1s to 5d contain 78 electrons								..	1	..	..	..	$^{2}S_{1/2}$	79
Hg	"								..	2	..	..	..	$^{1}S_{0}$	80
Tl	"								..	2	1	..	..	$^{2}P_{1/2}$	81
Pb	"								..	2	2	..	..	$^{3}P_{0}$	82
Bi	"								..	2	3	..	..	$^{4}S_{3/2}$	83
Po	"								..	2	4	..	..	$^{3}P_{2}$	84
—	"								..	2	5	..	..	$^{2}P_{3/2}$	85
Rn	"								..	2	6	..	..	$^{1}S_{0}$	86
—	Radon configuration. Shells 1s to 5d								..	The		..	1	$^{2}S_{1/2}$	87
Ra	contain 78 electrons								..	shells		..	2	$^{1}S_{0}$	88
Ac	"								..	6s to 6p		1	2	$^{2}D_{3/2}$	89
Th	"								1	contain		1	2	$^{3}H_{4}$	90
	"								..	8		2	2	$^{3}F_{2}$	..
UX	"								2	electrons		1	2	$^{4}K_{11/2}$	91
	"								..			3	2	$^{4}F_{3/2}$	..
U	"								3			1	2	$^{5}L_{6}$	92
	"								..			4	2	$^{5}D_{0}$	..

TABLE 602

EFFECTIVE ATOMIC RADII

Goldschmidt, on the basis of reasonable though empirical assumptions, has calculated effective radii f atoms in various charged conditions; Pauling, on the basis of wave-mechanics, has presented theoretical alues for most of the elements, the two series agreeing well in many cases. The latter values are printed n bold-faced type; the values considered nontypical are in parentheses; e.g., for silicon we have: Si^{+4} .22−) 0.39–**0.41.** Si° (1.12−) 1.18. Si^{-4} (1.98); **2.71,** signifying silicon, carrying 4 + charges, has pparent radius between 0.22 and 0.41; but the lower values relate to compounds where the atoms ppear to be deformed; so Goldschmidt gives 0.39 as most significant. Wave-mechanics yields **0.41.** Neutral, the radius ranges from 1.12, in abnormal compounds, to 1.18 in those typical; when carrying − charges, the value is 1.98, according to calculations deemed faulty, **2.71** according to theory.

In applying the data to replacements, halides and oxides are usually ionized, and the values in the uter columns apply. Thus in fluorite the value for Ca^{+2} should be added to that for F^{-1}, giving between .32 and 2.42, or 2.37 as a mean; and the observed Ca-F distance in the crystal is 2.36 Angstrom units. n the remaining types of compounds the atoms appear to be largely neutral and the first column should e used. The units are Angstroms. Wherry, Amer. Mineralog., 14, 54, 1929.

Atomic no.; element	Radius neutral atom Angstroms	Charge	Radius positively charged ion Angstroms	Atomic no.; element	Radius neutral atom Angstroms	Charge	Radius positively charged ion Angstroms
1 H				42 Mo	1.36	6	**0.62**
2 He	(0.93)			Mo		4	**0.66**(−0.83)
3 Li	(1.50−)1.56	1	**0.60**–0.78(−0.82)	44 Ru	1.27–1.34	4	**0.63**–0.65
4 Be	1.05(−1.15)	2	**0.31**–0.34	45 Rh	1.34–1.35	3	0.69
5 B		3	**0.20**	46 Pd	1.37		
6 C	(0.45−)0.77	4	**0.15**	47 Ag	(1.17−)1.44	1	(0.79−)1.13–**1.26**
7 N	(0.65−)0.71	5	**0.11**	48 Cd	(1.47−)1.49(−1.60)	2	(0.78−)**0.97**–1.03
8 O	0.60(−0.65)	6	**0.09**	49 In	1.45–1.62	3	**0.81**–0.92
9 F	0.67	7	**0.07**	50 Sn	(1.27−)1.40	4	(0.64−)**0.71**(−0.81)
10 Ne	(1.12)			51 Sb	(1.22−)1.34(−1.44)	5	**0.62**
11 Na	(1.77−)1.86	1	**0.95**–0.98(−1.09)	Sb		3	0.90
12 Mg	(1.42−)1.62	2	**0.65**–0.78(−0.85)	52 Te	1.33–1.43	6	**0.56**
13 Al	(1.16−)1.43	3	**0.50**–0.57(−0.66)	Te		4	**0.81**–0.89
14 Si	(1.12−)1.18	4	(0.22−)0.39–**0.41**	53 I	1.36–1.40	7	**0.50**
15 P	0.93	5	**0.34**	I		5	0.94
16 S	1.02–1.04	6	**0.29**–0.34	54 Xe	(1.90)		
17 Cl	1.05–1.07	7	**0.26**	55 Cs	(2.37−)2.55	1	1.65–**1.69**(−1.75)
18 A	(1.54)			56 Ba	2.10	2	1.35–1.43(−1.49)
19 K	(2.07−)2.23	1	1.33(−1.84)	57 La		3	**1.15**–1.22
20 Ca	(1.70−)1.97	2	0.99–1.06(−1.50)	58 Ce	1.82–1.83	4	**1.01**–1.02
21 Sc	1.51	3	**0.81**–0.83	Ce		3	1.18
22 Tl	(1.40−)1.49(−1.53)	4	(0.58−)0.64–**0.68**	59 Pr		4	**0.92**–1.00
23 V	1.32(−1.43)	5	**0.59**	Pr		3	1.16
V		4	**0.59**–0.61	60 Nd		3	1.15
24 Cr	(1.17−)1.25(−1.54)	6	**0.52**–0.65	62 Sm		3	1.13
25 Mn	(1.17−)1.29(−1.59)	7	**0.46**	63 Eu		3	1.13
Mn		4	**0.50**–0.52	64 Gd		3	1.11
Mn		2	**0.80**–0.91	65 Tb		3	1.09
26 Fe	(1.21−)1.26(−1.45)	3	(0.49−)0.67	66 Dy		3	1.07
Fe		2	**0.75**–0.83	67 Ho		3	1.05
27 Co	1.26(−1.39)	3	0.29–0.47	68 Er		3	1.04
Co		2	**0.72**–0.82	69 Tm		3	1.04
28 Ni	1.24(−1.39)	3	0.35	70 Yb		3	1.00
Ni		2	**0.69**–0.78	72 Hf	1.66		
29 Cu	(1.22−)1.27(−1.37)	2	0.70	73 Ta	1.42–1.44		
Cu		1	(0.58−)**0.96**	74 W	1.37	6	0.88
30 Zn	1.31–1.34	2	**0.74**–0.83	W		4	**0.66**–0.68
31 Ga	(1.28−)1.33(−1.45)	3	**0.62**	76 Os	1.30–1.34	4	**0.65**–0.67
32 Ge	1.22	4	0.44–**0.53**	77 Ir	1.35	4	**0.64**–0.66
33 As	(1.04−)1.16(−1.26)	5	**0.47**	78 Pt	1.38(−1.43)		
As		3	0.69	79 Au	1.40–1.44	1	**1.37**
34 Se	1.13–1.17	6	**0.42**	80 Hg	1.46–1.49	2	**1.10**–1.12
35 Br	1.19	7	**0.39**	81 Tl	(1.71−)1.99(−2.25)	3	**0.95**–1.05
36 Kr	(1.69)			Tl		1	1.44–1.51
37 Rb	(2.25−)2.36	1	**1.48**–1.49(−1.88)	82 Pb	1.74(−1.90)	4	**0.84**
38 Sr	1.95	2	**1.13**–1.27(−1.45)	Pb		2	(0.98−)**1.21**–1.32
39 Y		3	**0.93**–1.06	83 Bi	(1.34−)1.46(−1.55)	5	**0.74**
40 Zr	1.60–1.62	4	(0.68−)**0.80**–0.89	90 Th	1.80–1.82	4	**1.02**–1.10
41 Cb	1.43(−1.50)	5	0.69–**0.70**	92 U		4	**0.97**–1.05
Cb		4	**0.67**–0.69	−NH_4		1	**1.42**–1.59

	Charge	Radius negative ion		Charge	Radius negative ion		Charge	Radius negative ion		Charge	Radius negative ion
1 H	−1	(1.27); **2.08**	14 Si	−4	(1.98); **2.71**	32 Ge	−4	**2.72**	50 Sn	−4	(2.15); **2.94**
			15 P	−3	**2.12**	33 As	−3	**2.22**	51 Sb	−3	**2.45**
6 C	−4	**2.60**	16 S	−2	1.74–**1.84**	34 Se	−2	1.91–**1.98**	52 Te	−2	2.03–**2.21**
7 N	−3	1.71	17 Cl	−1	**1.81**	35 Br	−1	**1.95**–1.96	53 I	−1	**2.16**–2.20
8 O	−2	1.32–**1.40**									
9 F	−1	1.33–**1.36**							82 Pb	−4	**2.15**

ELECTRONS, PROTONS, ATOMIC STRUCTURE

Free negative electron (corpuscle, J. J. Thomson).—Mass, spectroscopic (bound) 9.035×10^{-28} g; free, 8.994×10^{-28} g; atomic weight, 5.479 and 5.454×10^{-4} respectively, probably all electrical, due to inertia of self-induction. Theory shows that when speed of electron = 1/10 velocity of light, its mass should be appreciably dependent upon that speed. If m_0 be the mass for small velocity, m, the transverse mass for v, and v/(velocity of light, c) = β then $m = m_0 (1 - \beta^2)^{-\frac{1}{2}}$ (Lorentz, Einstein).

β,	0.01	0.10	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
m/m_0,	1.00005	1.005	1.02	1.048	1.091	1.155	1.250	1.400	1.667	2.294

Radium ejects electrons with 3/10 to 98/100 of c. m, due to charge = $2E^2/3a$, where E = charge, a, radius, whence radius of electron is 2×10^{-13} cm = 1/50,000 atomic radius. Cf. (radius earth/radius Neptune's orbit) = 1/360,000. Collisions with α particles show diameter of electron must be less than 4×10^{-13} cm (Chadwick, Bieler, Philos. Mag., 1921).

Positive electron or proton.—Heavy, extraordinarily small, never found associated with mass less than that of the H atom; mass, 1.6609×10^{-24} g. Specific charge, 9579.7 abs-em-units $\cdot$ g^{-1}. Ratio mass proton to mass electron, 1838 (spectroscopic), 1847 (deflection). If mass is all electrical, radius must be 1/2000 that of electron. No experimental evidence as with the latter since high enough speeds not available. Penetrability of atom by β particle (may penetrate 10,000 atomic systems before it happens to detach an electron) and α particle (8000 times more massive than negative electron, passes through 500,000 atoms without apparent deflection by nucleus more than 2 or 3 times) shows extreme minuteness. Upper limit of nucleus not larger than 10^{-12} cm for Au (heavy atom) and 10^{-13} cm for H (light atom) (Rutherford). Cf. (radius sun)/(radius Neptune's orbit) = 1/3000 but sun larger than planets. Hg atoms by billions may pass through thin-walled, highly-evacuated glass tube without impairing vacuum, therefore massive parts of atoms must be extremely small compared to volume of atom.

Rutherford atom.—Atoms of all elements are somewhat similarly built. At the center a charged nucleus of minute dimensions, responsible for most of the mass of the atom; this is surrounded by a distribution held in equilibrium by the force from the nucleus. Resultant nuclear charge = atomic or ordinal no., varies from 1 for H to 92 for U. These atomic nos. represent the number of planetary electrons which surround the nucleus. By the action of light, the electric charge, bombardment by α particles, one or more of the planetary electrons may be driven away from the nucleus; by X rays or the swift β rays some of the more strongly bound may be removed. New electrons are generally soon captured to replace these. The nucleus is much more stable and when disrupted (radioactive changes, bombardment with α particles) shows no tendency to revert to original state.

Moseley (Philos. Mag., 26, 1912: 27, 1914) photographed and analyzed X-ray spectra, showing their exact similarity in structure from element to element, differing only in frequencies, the square roots of the frequencies forming an arithmetical progression from element to element. Moseley's series of increasing X-ray frequencies is with one or two

ELECTRONS, PROTONS, ATOMIC STRUCTURE

exceptions that of increasing atomic weights, and these exceptions are less anomalous for the X-ray series than for the atomic-weight series. It seems plausible that there are 92 elements (from H to U) built up by the addition of some electrical element. Moseley assigned successive integers to this series (see Table 598) known now as atomic numbers.

Moseley's discovery may be expressed in the form

$$n_1/n_2 = E_1/E_2 \text{ or } \lambda_2/\lambda_1 = E_1^2/E_2^2$$

where E is the nuclear charge and λ the wave length. Substituting for the highest frequency line of W, $\lambda_2 = 0.167 \times 10^{-8}$cm (Hull), $E_2 = 74 = N_w$, and $E_1 = 1$, then $\lambda_1 =$ highest possible frequency by element which has one + electron; $\lambda_1 = 91.4 \mathrm{m}\mu$. Now the H ultra-violet series highest frequency line $= 91.2 \mathrm{m}\mu$ (Lyman); i. e., this ultra-violet line of H is nothing but its K X-ray line. Similarly, it seems equally certain that the ordinary Balmer series of H (head at $365 \mathrm{m}\mu$) is its L X-ray series and Paschen's infra-red series its M X-ray series.

The application of Newton's law to Moseley's law leads to $E_1/E_2 = a_2/a_1$, where the *a's* are the radii of the inmost — electronic orbits, i. e., the radii of these orbits are inversely proportional to the central charges or atomic numbers.

There are other negative electrons on the nucleus with corresponding + charges to make the atom neutral electrically. The negative nuclear charges may serve to hold the positive ones together. He, atomic no. = 2, has two free + charges, on nucleus; the nucleus has 4 + protons held together by 2 — electrons with 2 — electrons outside nucleus. H has one + proton and one — electron.

If the — electron is designated as e (charge — 1, mass negligible) and the + proton as p (charge + 1, mass 1 except in H) then the formula for the nucleus of any element from He to U may be written as $(p_2e)_N(pe)_n$ where N is the atomic number and n has values from 0 to 54. If n be taken as — 1, then H may be included. (Masson, Philos. Mag., 41, 1921.) If brackets are used to designate the nucleus then the complete element becomes $[(p_2e)_N(pe)_n]e_N$. In the formation of ions only the part exterior to the brackets is affected. For the α-transformation (emission of + charged He nucleus) $2(p_2e) = (p_2e)_2\nearrow$, the subchemical equation may be written $[(p_2e)_N(pe)_n]e_N = [(p_2e)_N - 2(pe)_n]e_N + (p_2e)_2\nearrow$ (He nucleus); the new elements upon discharge of its — charge becomes $[(p_2e)_N - 2(pe)_n]e_N - 2$ showing the characteristic α-ray change with the atomic weight lowered by 2 and the mass by 4. The β-ray $2(pe) = (p_2e) + e\nearrow$ gives the equation

$$[(p_2e)_N(pe)_n]e_N = [(p_2e)_N + 1(pe)_{n-2} + e\nearrow$$

mass unchanged and forms the singly — charged ion of an isobar.

From the emission of nuclear α particles, $2(p_2e) = p_4e_2$, it seems probable that the nuclei are compounds of He and I nuclei. By the bombardment of the nuclei of atoms up to atomic number 40 with α particles Rutherford has obtained H but only where H and He nuclei should both occur in the nucleus (Bo, N, Fl, Na, Al, P, see Table 638). Harkins has

TABLE 603 (A) (*concluded*).—Electrons, Protons, Atomic Structure

developed this idea (Journ. Franklin Inst., 194, 213 et seq., 1922) and shown the much greater frequency in nature of the even-atomic numbered elements (97.6 per cent in stony meteorites, 99.2 Fe meteorites, 85.6 lithosphere, 5 unknown elements all odd, even radioactive most stable). Elements below atomic number 30 make up 99.99 per cent of all meteorites, 99.85 igneous rocks, 99.95 shale, 99.95 sandstones, 99.85 lithosphere. The stability of the He nucleus may be judged by the energy set free in the formation of He from H. According to "relativity" 1 g-mass $= 9 \times 10^{20}$ ergs ($E = mc^2$). The change of mass involved in the formation of 1 g-atom of He (4.000 g) from 4 g-atoms of H_2 (4×1.0078 g) $= 2.81 \times 10^{19}$ ergs $= 6.71 \times 10^{11}$ calories. 1 lb. H_2 changed to He equals heat from 10,000 tons coal. The nuclei of light even numbered atoms (most abundant isotope) up to Fe (26) almost wholly of He nuclei. To a 1st approximation the α particle behaves in collision like an elastic oblate spheroid, semi-axes, 8×10^{-12} and 4×10^{-13} cm (Chadwick, Bieler, Philos. Mag. 1921).

TABLE 603 (B).—Atomic Structure, Bohr Atom

Bohr atom.—Bohr postulated electrons rotating in circular nonradiating orbits about a central body according to the laws of celestial mechanics and its consequent energy relations. He added the idea that these electrons could jump between different orbits emitting light of a frequency ν which depended upon the relationship $E_2 - E_2 = h\nu$ where the E's denote the energies (according to classical conceptions) in the two orbits and h, Planck's "quantum of action" of the nature of a moment of momentum. In going from one possible orbit to another the moment of momentum of the electron *must* progress by steps, each a multiple of $h/2\pi$. Balmer's formula is consistent with such a process: $\nu = N(1/n_1^2 - 1/n^2)$ where ν is the frequency, N, a constant, and n_1 for the visible series (Balmer's) has the value 2, n, the successive integral values, 3, 4, 5, . . . ; 33 lines in the Balmer series have been observed in stars where orbits of greater radius are possible (small gas density) than in the laboratory (12 lines). With $n_1 = 1$, n, 2, 3, 4, . . ., Lyman's ultra-violet series results; $n_1 = 3$, n, 4, 5, 6, . . ., Paschen's infra-red series; $n_1 = 4$, n, 5, 6, 7, . . ., Brackett's series of even greater wave lengths.

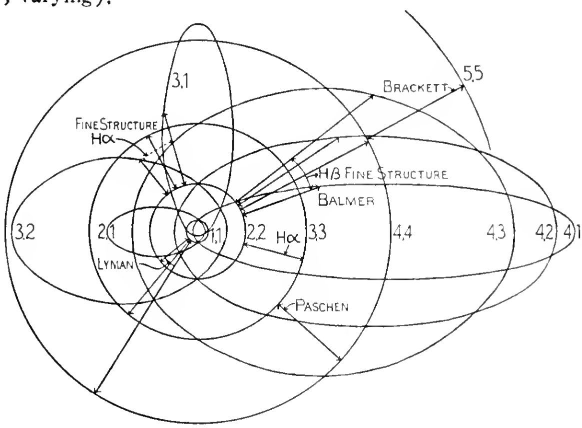
No mechanism was described to show how the energy of rotation was transferred into energy of radiation nor why only certain orbits could be occupied. He evidently used non-radiating orbits at variance with Maxwell's equations.

Two independent predictions from these assumptions were verified: the predicted and observed values of Rydberg's constant within $\frac{1}{4}$% and the differences in ν for the H and the He + lines due to the 4-fold mass of the He + nucleus.

Relativistic considerations.—Sommerfeld (1916) applied Einstein's relativity considerations together with the variation of mass with the speed of the revolving electrons and brought further support to the idea of orbits through prediction and the verification of the "fine structure of spectrum lines." Bohr considered only circular orbits in which the speed of rotation is constant, but elliptical orbits are possible with the same $h/2\pi$ as the circular and in them the speeds of revolution of the electrons change in different portions of the orbit as with classical mechanics but these speeds are such that a relativity

TABLE 603(B) (*continued*).—Atomic Structure, Bohr Atom

correction to the mass is necessary. Their quantization brought another quantum number; the so-called total quantum number, n, now becomes the sum of two since both the radii (r) and azimuth (ϕ) of the electron vary. The orbit is usually designated by two quantum numbers, the total, n, and the azimuthal (ϕ) viz: 1.1, 2.3 (p orbit, circular), 2.1 (s orbit, elliptical), 3.3, 3.2, 3.1. . . . . The following figure illustrates the first four sets of orbits of the hydrogen atom. The table indicates the modes of the quantum numbers (a_2 radius inner orbit, a, b, varying).



nk	total n	azim. k	radial n_r	a/a_2	b/a_1
1.1	1	1	0	1	1
2.1	2	1	1	4	2
2.2	2	2	0	4	4
3.1	3	1	2	9	3
3.2	3	2	1	9	6
3.3	3	3	0	9	9

The resonance potentials for the circular orbits are (hydrogen atom):

1.1 orbit to →	2.2	3.3	4.4	5.5	6.6	7.7	....	∞
Volts observed	10.15	12.05	12.70	13.00	13.17	13.27	....	13.54
λ Lyman series, μ	.1216	.1026	.0972	.0950	....	....	....	0912μ
" Balmer 2.2 orbit	....	.6563	.4861	.4340	.4102	.3970	....	.3646μ
" Paschen 3.3 orbit	....	....	1.8756	1.2821	1.0939	1.0052	....	.8203μ
" Brackett 4.4 orbit	....	....	....	4.05	2.63	2.16	....	1.46μ

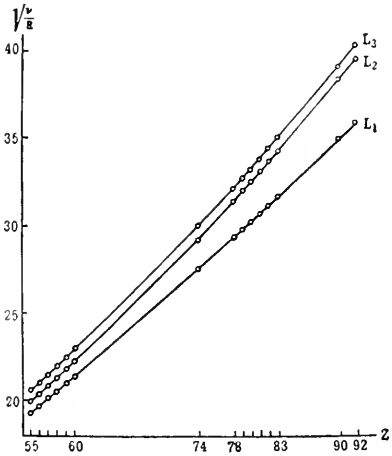
The remarkable prediction and consequent observation of the "fine-structure of spectrum lines resulted from this postulate." Thus all the lines of the Balmer series, consisting of jumps into the state of total quantum 2, possessing 2 orbits, a circle and an ellipse, should show a fine structure due to energy differences of these circular and elliptical orbits. Approximately they should be all doublet lines of wave length predictable from laws of orbital mechanics. The separations should be .365 cm^{-1}; actually .36 cm^{-1} (Houston) was found. The separation should vary as the 4th power atomic no. Paschen (1916) actually found for He +, 16 × .365 cm^{-1}. Further remarkable results came from Epstein's (Ann. Phys., 50, 489, 1916) work on the Stark effect and the prediction of the separation of the so-called L doublets of X-ray spectra. If actually a relativity doublet, one must multiply the H separation by 71 millions (92^4); also checked with experiment.

Inner quantum numbers.[1]—It became necessary (1920, Sommerfeld, Ann. Phys., 63, 221, 1920) to account for further fine structure. e. g.: In X rays the L orbits or levels correspond to $n = 2$, permitting only two different orbits, 2.2 (circle) and 2.1 (ellipse); but lines of 3 close wave lengths were observed—two being the regular expected doubtlet whose frequency varies with 2^4 as expected. These two levels are indicated by the two diverging lines, L_2, L_3 in the following figure.

[1] Millikan, Proc. Amer. Philos. Soc., 66, 211, 1927, from which much of the accompanying description is condensed.

TABLE 603(B) (*continued*).—Bohr Atom

The third level L_1 is seen to follow an entirely different law: it runs parallel to L_2.



Bohr and Sommerfeld introduced the idea of two orbits of the same shape but different orientations, something different in the central field giving these orbits slightly different energies. A so-called *inner* quantum number, J, was introduced. The difference in the frequencies of the familiar doublets in Li was supposed due to jumps to a common orbit (s orbit) from 2 orbits differing only in the "inner" quantum number, i. e., orbits of different orientations but same shapes, in this case circles, or 2.2 orbits, known as the p_1p_2 orbits. The s orbit into which the 2 electrons jumped to form the Li doublet was the third possible of total quantum 2, the 2.1 orbit. The two circular (p orbits) differed slightly in frequency, but the changes from either p to the s orbit was too large for the relativity effect. Bohr (Ann. Phys., 71, 228, 1923) suggested that the anomaly was due to the penetration of orbits of outer electrons within the field of action of inner orbits.

TABLE 603(C).—The Spinning Electron and Summary

The spinning electron.—A disconcerting element existed in that the difference of energy between two circular p_2p_2 orbits varied with the atomic number precisely as demanded by the relativity consideration, though it could not be due to relativity since the p_1p_2 orbits had no difference in shape but only of orientation. A new conception by Uhlenbeck and Goudsmit (Nature, 117, 264, 1926) came to the rescue assuming that every electron rotates upon its axis. Two possible directions of spin are assumed 180° apart, but the moment of momentum is assumed always the same, exactly $\frac{1}{2}$ unit or $\frac{1}{2}\ h/2\pi$. This introduces exactly the right amount of energy difference between the p_1p_2 circular orbits. It is superposed upon the relativity effect, making the fine structure (even in H and He+ without inner electronic orbits) somewhat more complex.

In the case of each individual electron there are four moments of momentum—four elements to describe an electron's orbital motion:

(1) The size of its orbit—the total moment of momentum characterized by its total quantum number n (Bohr) fixing the major axis of orbit.

(2) The azimuthal quantum number, k, which with a given n or major axis, fixes the shape (minor axis). It has been found expedient to reduce by unity all values of k heretofore assigned. Since we are not ready to discard entirely the old interpretation, this reduced value of k is for convenience denoted by a new letter, l, so that $l = k - 1$. Thus for an s orbit $l = 0$; p orbit, 1; d orbit, 2; etc.

(3) The projection of the moment of momentum l upon any fixed direction, which, in considering the Zeeman effect is the direction of the external magnetic field, is quantized (m_l). The projection fixes the orientation in space. The significance that this projection is quantized is that only certain definite orientations are possible (Stern, Gerlach experiments).

(4) The projection of the moment of momentum of spin upon this fixed direction is designated by the symbol m_r. In each atom only two possible directions of spin 180° apart are taken so that m_r determines in what direction the electron is spinning. m_l and m_r are usually called magnetic quantum numbers because of their use in connection with magnetic fields.

(Most of the above is abbreviated from Millikan, Proc. Amer. Philos. Soc., 66, 211, 1927.)

Table 604

ENERGY OF BINDING OF AN ELECTRON—NEUTRAL ATOMS

(Adapted from paper by Henry Norris Russell, Astrophys. Journ., 70, 1929.)

The electrons in an atom, neutral or ionized, are bound in different states (a preferable term to "orbits"). The more firmly bound inner ones which form parts of the completed shells concern the spectroscopy of X rays but not of ordinary light. The two following tables give a study of the energy of binding of an electron, in different atoms, in the same state, the state characterized by the same total and azimuthal quantum numbers, denoted in Bohr's notation by 1_1, 2_1, 3_1,—; 2_2, 3_2, 4_2,—; 3_3, 4_3,—; 4_4,—, or more commonly at present, 1s, 2s, 3s,—; 2p, 3p, 4p,—; 3d, 4d,—; 4f,—. The energy in volts is given required to remove an electron in the given state from the atom or liberated when it returns. Among the energy levels resulting from different space quantizations of the same electronic configuration, that with the greatest binding energy is given regardless of the multiplicity. Most values are derived from spectrum series and are fully reliable; those in ( ), two decimals, are extrapolations from series formulae and should be substantially correct; those in ( ), one decimal and in [ ] are interpolated and should be accurate to 0, to 0.2 v.

El.	1s	2s	2p	3s	3p	3d	4s	4p	4d	5s	5p	5d
H	13.54	3.38	3.38	1.50	1.50	1.50	0.81	0.81	0.81	0.54	0.54	0.54
He	24.48	4.75	3.61	1.86	1.57	1.51	.99	.87	.85	.61	.56	.54
Li	....	5.36	3.40	2.01	1.55	1.51	1.05	.87	.85	.64	.55	.54
Be	....	9.29	6.57	2.86	....	1.62	1.32	....	.90	.76	....	.57
B	....	....	8.28	3.34	....	1.52	1.49	....	.87	....	....	.57
C	....	....	11.22	3.78	2.42	1.57	....	1.19	....	....	....	....
N	....	....	14.50	4.20	2.78	1.55	1.69	....	.87	.93	....	.56
O	....	....	13.56	4.45	2.86	1.52	1.77	1.32	.86	.95	....	.55
F	....	....	[17.3]	(4.7)	(3.0)	....	....	....	....	....	....	....
Ne	....	....	21.47	4.93	3.17	1.53	1.86	1.41	.86	1.00	.80	.55
Na	....	....	....	5.11	3.02	1.51	1.94	1.38	.85	1.02	.79	.54
Mg	....	....	....	7.61	4.92	1.88	2.52	1.70	1.05	1.21	.92	.66
Al	....	....	....	....	5.95	1.95	2.83	1.89	1.15	1.31	.99	.75
Si	....	....	....	....	8.14	....	3.08	....	1.16	1.37	....	....
P	....	....	....	....	[10.5]	....	(3.5)	....	....	....	....	....
S	....	....	....	....	10.31	(1.98)	3.82	2.48	1.06	(1.59)	1.19	.65
Cl	....	....	....	....	[12.9]	....	(3.9)	[2.6]	....	....	....	....
A	....	....	....	....	15.69	(1.93)	4.19	2.84	1.06	1.69	1.29	.65
K	....	....	....	....	....	1.65	4.33	2.72	.94	1.72	1.27	.59
Ca	....	....	....	....	....	3.57	6.09	4.21	1.42	2.19	1.57	.81
Sc	....	....	....	....	....	5.13	6.57	4.59	1.66	2.40	....	....
Ti	....	....	....	....	....	5.95	6.80	4.76	1.60	2.32	....	....
V	....	....	....	....	....	6.68	7.04	4.92	....	2.35	....	....
Cr	....	....	....	....	....	8.24	7.28	5.05	....	2.43	....	....
Mn	....	....	....	....	....	5.76	7.40	5.09	1.64	2.54	....	....
Fe	....	....	....	....	....	6.98	7.83	5.45	1.63	2.55	....	....
Co	....	....	....	....	....	7.82	8.25	5.33	....	2.62	....	....
Ni	....	....	....	....	....	8.63	8.65	5.25	1.65	2.55	....	....
Cu	....	....	....	....	....	10.41	9.02	5.58	1.65	2.69	....	....
Zn	....	....	....	....	....	....	9.36	5.30	1.66	2.72	1.80	.89
Ga	....	....	....	....	....	....	....	5.98	1.68	2.92	1.89	.94
Ge	....	....	....	....	....	....	....	7.89	1.87	3.26	....	1.04
As	....	....	....	....	....	....	....	[9.6]	....	(3.4)	....	....
Se	....	....	....	....	....	....	....	[9.4]	(1.9)	(3.4)	....	(0.8)
Br	....	....	....	....	....	....	....	[11.4]	....	(3.6)	....	....
Kr	....	....	....	....	....	....	....	[13.9]	....	(3.9)	....	....
Rb	....	....	....	....	....	....	....	....	1.76	4.13	2.60	.88
Sr	....	....	....	....	....	....	....	....	3.42	5.65	3.82	1.34
Yt	....	....	....	....	....	....	....	....	5.04	6.40	4.55	1.61

Table 605

ENERGY OF BINDING OF AN ELECTRON—SINGLY IONIZED ATOMS

(Adapted from Henry Norris Russell, Astrophys. Journ., 70, 1929.)

This table companions the preceding one. A number of entries have been derived in various ways and may be in error by .5 volt; Li +, 3–4 v. The lines of a diagram made from the data of these two tables, with atomic numbers as abscissae and energy of binding as ordinates, a separate line for each state, are strikingly similar. The familiar "displacement law" applies not only to the multiplicities present in the spectrum, but also to the energy relations—the spark spectrum for any element resembling in both respects that of the arc of the preceding element.

The energy of binding, for a given state, increases with the atomic number. For the s states the increase is steady; for the p and d states it is interrupted by fluctuations remarkably similar.

The increase of energy is most rapid (1) when electrons of a given type are building up a complete shell; (2) when s electrons are being added. The fluctuations are most conspicuous when a shell is half full (half of the 6p electrons in N, P, As, O^+, S^+, and of the 10d electrons in Cr, Mn^+).

Energy of Binding of an Electron—Singly Ionized Atoms

El.	1s	2s	2p	3s	3p	3d	4s	4p	4d	5s	5p	5d
He^+	54.16	13.54	13.54	6.02	6.02	6.02	3.38	3.38	3.38	2.16	2.16	2.16
Li^+	(80)	16.58	14.70	6.83	6.24	6.03	3.72	3.48	3.39	2.33	2.22	2.17
Be^+	....	18.13	14.18	7.25	6.27	6.03	3.88	3.47	3.40	2.41	2.21	2.17
B^+	....	23	20.41	9.00	7.27	6.43	4.52	....	3.56	....	....	....
C^+	....	....	24.28	9.90	8.01	6.31	4.87	4.22	3.52	2.85	....	2.24
N^+	....	....	29.50	11.10	8.93	6.45	5.22	....	3.54	3.04	....	....
O^+	....	....	34.94	12.09	9.76	6.37	5.44	....	....	3.10	....	....
F^+	....	....	[34.9]	(13.1)	....	....	....	....	....	....	....	....
Ne^+	....	....	40.89	13.74	10.40	6.33	5.98	....	....	....	....	....
Na^+	....	....	47.02	14.31	10.83	6.20	6.18	....	....	....	....	....
Mg^+	....	....	....	14.97	10.56	6.13	6.33	5.01	3.34	3.51	2.94	2.20
Al^+	....	....	....	18.74	14.12	8.19	7.48	5.73	5.15	3.92	3.22	3.34
Si^+	....	....	....	....	16.27	6.46	8.24	6.25	3.80	4.18	3.44	2.40
P^+	....	....	....	....	19.81	6.95	9.11	7.08	4.07	4.58	....	....
S^+	....	....	....	....	23.32	9.70	9.80	7.51	4.54	4.75	....	....
Cl^+	....	....	....	....	[23.9]	10.25	10.56	7.98	4.79	5.08	....	....
A^+	....	....	....	....	27.62	11.23	11.00	8.42	4.90	5.16	....	....
K^+	....	....	....	....	31.68	11.50	11.62	9.07	5.43	5.08	....	....
Ca^+	....	....	....	....	....	10.14	11.82	8.72	4.80	5.37	4.35	2.84
Sc^+	....	....	....	....	....	12.19	12.80	9.58	5.40	5.68	....	....
Ti^+	....	....	....	....	....	13.45	13.60	9.98	5.55	5.90	....	....
V^+	....	....	....	....	....	(14.7)	(14.4)	(10.3)	....	....	....	....
Cr^+	....	....	....	....	....	(16.6)	(15.1)	(10.7)	....	....	....	....
Mn^+	....	....	....	....	....	13.93	15.70	10.91	5.85	6.50	....	....
Fe^+	....	....	....	....	....	(16.3)	(16.5)	(11.7)	....	....	....	....
Co^+	....	....	....	....	....	(17.2)	(16.8)	(11.7)	....	....	....	....
Ni^+	....	....	....	....	....	18.19	17.15	11.75	....	7.20	....	....
Cu^+	....	....	....	....	....	20.34	17.62	12.13	....	6.99	....	....
Zn^+	....	....	....	....	....	....	17.89	11.79	5.92	6.97	5.40	3.35
Ga^+	....	....	....	....	....	....	(18.8)	14.00	5.68	7.14	....	....
Ge^+	....	....	....	....	....	....	....	15.98	6.00	8.28	6.21	3.62

Table 606

FIRST IONIZATION POTENTIALS OF THE ELEMENTS

(Russell, Astrophys. Journ., 70, 1929; Mt. Wilson Contr. 383.)

In discussing the relative strength of the arc and enhanced lines a knowledge of ionization potentials is necessary. These are implicitly contained in Tables 604 and 605. Generally the energy difference between the normal states of the neutral atom and ion is required; complications arise in the Fe group. Table 604 gives the energy difference between the 4s state of the ion ($d^{n-2}s$) and the various states of the neutral atom, of which we must evidently choose the lowest, whether it be $4s(d^{n-2}s^2)$ or $3d(d^{n-1}s)$. Sometimes the $3d(d^{n-1})$ state of the ion is the lowest, and the values of Table 604 must be corrected. For the 2nd ionizations no such complication arises. Both tables include heavier elements for which data are at hand. Each is divided into two sections, corresponding to the "building on" of shells of s and d, or of p electrons. He, Be, Mg are put on line with Zn, Cd, Hg, because their spectra resemble those of the latter much more closely than those for Ca, Sr, Ba. The line below La marks the position of the rare earths, where 14 4f electrons are added which are listed separately.

While each shell of outer electrons is being completed, the ionization potential increases (minor irregularities occur for space quantization or interchange of s and d configurations. Maximum occurs when a shell is filled). The drop after the filling of an s shell in Be and Mg is between 1 and 2 volts; after completion of the combined s and d shells in Zn, Cd, Hg, it is 3 or 4 volts, while that following the completion of a p shell in the inert gases is much greater—8 to 16 volts. For the 2nd ionization, these discontinuities are greater in absolute value, but are a smaller fraction of the potentials themselves. (Continued on next page.)

First Ionization Potentials of the Elements

H	13.59	Li	5.36	Na	5.11	K	4.33	Rb	4.13	Cs	3.86	Ce	6.9
						Ca	6.09	Sr	5.65	Ba	5.19	Pr	5.8
						Sc	6.57	Yt	6.5	La	5.5	Nd	6.3
						Ti	6.80	Zr	..	Hf	..	Il	..
						V	6.76	Cb	..	Ta	..	Sa	6.6
						Cr	6.74	Mo	7.35	W	8.1	Eu	..
						Mn	7.40	Ma	..	Re	..	Gd	6.7
						Fe	7.83	Ru	7.7	Os	..	Tb	6.7
						Co	7.81	Rh	7.7	Ir	..	Dy	6.8
						Ni	7.64	Pd	8.28	Pt	9.2	Ho	..
						Cu	7.69	Ag	7.33	Au	9.20	Er	..
He	24.48	Be	9.29	Mg	7.61	Zn	9.36	Cd	8.95	Hg	10.39	Tu	..
		B	8.28	Al	5.95	Ga	5.98	In	5.76	Tl	6.08	Yb	7.1
		C	11.22	Si	8.14	Ge	7.89	Sn	7.37	Pb	7.38	Lu	..
		N	14.50	P	[10.5]	As	[9.6]	Sb	8.35	Bi	7.25		
		O	13.56	S	10.31	Se	[9.4]	Te	[8.7]	Po	..		
		F	[17.3]	Cl	[12.8]	Br	[11.4]	I	[10.2]	..	..		
		Ne	21.47	A	15.69	Kr	[13.9]	Xe	[12.1]	Rn	..		

Table 607

SECOND IONIZATION POTENTIALS OF THE ELEMENTS

(Russell, Astrophys. Journ., 70, 1929, Mt. Wilson Contr. 383.)

(Continued from previous page)

The general character of the spectra of most of the heavier elements can be deduced from Tables 604 and 605. For the 2nd long period (Rb-Xe) the ionization potentials are nearly the same as for homologous elements in the first, but average a little lower. The same is true, in general, regarding the other energy levels, so that the arc and spark spectra of these elements show high- and low-excitation lines in the same regions for those of the first long period, but on the whole, a little farther to the red.

At the start of the next period, we find the lowest-known ionization potentials (Cs and Ba + for the second stage), which remain lower than in other periods until the rare-earth group begins. In these elements the outer electrons are two 6s, one 5d, and from one to 14 4f electrons, the ionization potential slowly rising as the 4f group is built up. For the earlier members, the lines of the ionized atom are the main features of the arc spectrum; those of the neutral atom are best brought out in the furnace; first ionization potentials are very low. The strong lines of the first spark spectrum shift towards the violet with increasing atomic numbers, practically proving that the second ionization potential also increases. The number of atomic-energy states should be much greater among the rare earths than for other elements. Their spectra are very intricate.

The shell of 4f electrons completed, the ionization potential ceases to have any important effect on the properties of the elements; note their chemical behavior and what is known of their spectra (Hf+, W). A considerable fall in the ionization potential should occur between the last rare earth, Lu, and Hf, and a gradual rise to Au and Hg. For Au and Hg ionization is more difficult than for the homologous elements in the preceding periods.

Second Ionization Potentials

He^+	54.16	Be^+	18.13	Mg^+	14.97	Ca^+	11.82	Sr^+	10.98	Ba^+	9.96	Ra^+	10.2
						Sc^+	12.80	Yt^+	12.3	La^+	. .	Ac^+	. .
						Ti^+	13.60	Zr^+	. .	Hf^+	. .	Th^+	. .
						V^+	(14.7)	Cb^+	. .	Ta^+	. .	Pa^+	. .
						Cr^+	(16.6)	Mo^+	. .	W^+	. .	U^+	. .
						Mn^+	15.70	Ma^+	. .	Re^+	. .		
						Fe^+	(16.5)	Ru^+	. .	Os^+	. .		
						Co^+	(17.2)	Rh^+	. .	Ir^+	. .		
						Ni^+	18.19	Pd^+	19.8	Pt^+	. .		
						Cu^+	20.34	Ag^+	21.9	Au^+	. .		
						Zn^+	17.89	Cd^+	16.82	Hg^+	18.9		
Li^+	(80)	B^+	(23)	Al^+	18.74	Ga^+	(18.8)	In^+	. .	Tl^+	20.0		
		C^+	24.28	Si^+	16.27	Ge^+	15.98	Sn^+	14.5	Pb^+	14.96		
		N^+	29.50	P^+	19.81	As^+	. .	Sb^+	. .	Bi^+	. .		
		O^+	34.94	S^+	23.32	Se^+	. .	Te^+	. .	Po^+	. .		
		F^+	[34.9]	Cl^+	[23.9]	Br^+	. .	I^+	. .	. .	. .		
		Ne^+	40.89	A^+	27.62	Kr^+	26.4	Xe^+	. .	Rn^+	. .		
		Na^+	47.02	K^+	31.68	Rb^+	. .	Cs^+	. .	. .	. .		

TABLE 608.—Radiation Units

Radio, meter	Radiation, micron	Colorimetry, millimicron	Spectroscopy, Angstrom	X rays, milliangstrom	γ rays, microangstrom

Units		Powers-of-10 equivalent of units listed in column 1							
Name	Symbol	μ	$m\mu$	A	mA	μA	c.g.s. unit cm	mm	m
Micron	μ	1	10^{3}	10^{4}	10^{7}	10^{10}	10^{-4}	10^{-3}	10^{-6}
Millimicron	$m\mu$	10^{-3}	1	10	10^{4}	10^{7}	10^{-7}	10^{-6}	10^{-9}
Angstrom	A	10^{-4}	10^{-1}	1	10^{3}	10^{6}	10^{-8}	10^{-7}	10^{-10}
Milliangstrom	mA	10^{-7}	10^{-4}	10^{-3}	1	10^{3}	10^{-11}	10^{-10}	10^{-13}
Microangstrom	μA	10^{-10}	10^{-7}	10^{-6}	10^{-3}	1	10^{-14}	10^{-13}	10^{-16}

TABLE 609.—Spectrum Ranges of Various Radiations

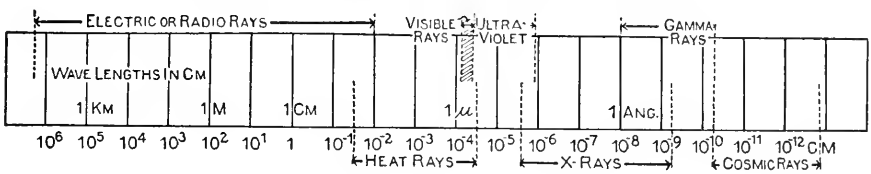


TABLE 610.—The Mechanical Effects of Radiation

(Jeans, Nature, 118, 1926, taken from Bull. 80, Nat. Res. Council, 1931.)

Wave lengths, cm	Nature of radiation	Effect on atom	Temperature (degrees absolute)	Where found
7500×10^{-8} – 3750×10^{-8}	Visible light	Disturbs outermost electrons.	3880 to 7700	Stellar atmospheres.
250×10^{-8} – 10^{-8}	X rays	Disturb inner electrons.	115,000 to 29,000,000	Stellar interiors.
5×10^{-9} – 10^{-9}	Soft γ rays	Strip off all or nearly all electrons.	58,000,000 to 290,000,000	Central regions of dense stars.
4×10^{-10}	γ rays of *RaB*	Disturb nuclear arrangement.	720,000,000	?
5×10^{-11}	Hardest γ rays	. . . . . .	58×10^{8}	
4.5×10^{-12}	?	Building of He atom out of H.	64×10^{9}	
2×10^{-12}	Highly penetrating	Disintegrates nuclei.	15×10^{10}	
1.3×10^{-13}	?	Annihilation or creation of proton and accompanying electron.	22×10^{11}	

TABLE 611

NORMAL SERIES RELATIONS IN ATOMIC SPECTRA

(From manuscript by Henry Norris Russell, 1932.)

Every spectral line is believed to be emitted (or absorbed) in connection with the transition of an atom between two definite (quantized) states, of different energy-content—the frequency of the emitted or absorbed radiation being exactly proportional to the change of energy. The wave number (or frequency) of the line may therefore be expressed as the difference of two *spectroscopic terms* which measure, in suitable units, the energies of the initial and final states. It is customary to use in place of true frequency ($sec.^{-1}$) the wave number (cm^{-1}), i. e., the number of waves in one centimeter in a vacuum. All quantities of the nature of frequency or energy are most conveniently expressed in cm^{-1} units. The multiplication of such values by c ($= 2.99796 \times 10^{10}$ cm. $sec.^{-1}$) gives the true frequency in $sec.^{-1}$ and by hc ($= 1.9658 \times 10^{-16}$ erg cm) gives the true energy in ergs. Combinations between these terms occur according to definite laws, which enable us to classify them into systems, each containing a number of series of terms, which are usually multiple. The energy is often measured in "electron volts," one of which $= 8106\ cm^{-1}$.

Terms, and the corresponding energies, may be measured either *upward* from the lowest energy state of the atom (in a given degree of ionization), or *downward* from a series limit (see below).

Series of terms are found in many spectra which satisfy the relation

$$y = z^2R/(n + x)^2$$

Here y is the term-value, measured *downward* from the appropriate limit; $z = 1, 2, 3 \ldots$ for neutral, singly, doubly, ionized atoms; R is the Rydberg constant, and n a "running" integer, which changes by 1 from one member of the series to the next. The "residual" x is often nearly constant (Rydberg's formula). Ritz's formula $x = \mu + \alpha y$ (μ, α, constants) is usually a good approximation though not rigorous.

In the simplest spectra (e. g., Na, Ca^+) all the series have the same limit (corresponding to an isolated lowest energy state of the atom in its next higher degree of ionization) and long series of terms are known. But in most spectra there are many limits, corresponding to different states of the more highly ionized atom: few members of any given series are observed, and these perturb one another so that the Ritz formula no longer holds good.[1] The interpretation of these spectra depends upon the combination relations, formulated mainly by Sommerfeld and Landé, and the relations between electron configurations and term structure which have been put into definitive form by Hund.[2] These relations may be summarized as follows:

(a) The terms (or energy levels) of any given atom fall into two main groups of different *parity* (odd and even). Transitions producing spectral lines normally occur only between an odd and an even term. Those between terms of the same parity are "forbidden" but may occur under exceptional circumstances (as in gaseous nebulae).

(b) Terms of the same parity fall into *systems*—singlets, doublets, triplets, etc., characterized by the multiplicity R—the maximum number of components which a term may possess.

(c) In each system are found terms of various types denoted by the letters S, P, D, F, G, H, I. . . . . The number of components increases along the series 1, 3, 5, but stops short at the maximum R (whether odd or even) characteristic of the system. The successive terms of a given series are always of the same multiplicity, type, and parity: but other terms of the same sort may be interpolated among them.

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[1] Compare Shenstone and Russell, Phys. Rev., 39, 415, 1932.
[2] Linienspektren der Elemente, 1927.

NORMAL SERIES RELATIONS IN ATOMIC SPECTRA (*continued*)

(d) The components of a term are characterized by *inner quantum numbers* J, and the terms themselves by quantum numbers L, according to the following scheme.

TABLE 612.—Inner Quantum Numbers

Type	L	Values of J for					
		Singlets	Doublets	Triplets	Quartets	Quintets	Septets
S	0	0	½	1	1½	2	2½
P	1	1	½ 1½	0 1 2	½ 1½ 2½	1 2 3	1½ 2½ 3½
D	2	2	1½ 2½	1 2 3	½ 1½ 2½ 3½	0 1 2 3 4	½ 1½ 2½ 3½ 4½
F	3	3	2½ 3½	2 3 4	1½ 2½ 3½ 4½	1 2 3 4 5	½ 1½ 2½ 3½ 4½ 5½
G	4	4	3½ 4½	3 4 5	2½ 3½ 4½ 5½	2 3 4 5 6	1½ 2½ 3½ 4½ 5½ 6½

Line-producing combinations occur only between components for which the difference ΔJ is 0 or ± 1. The combination of two multiple terms thus gives rise to a group of lines called a *multiplet*.

(e) In such a group the lines for which $\Delta J = \Delta L$ are the strongest (often called the diagonal lines) and the line for which the J's are largest is the strongest of these. These intensity relations (which have been calculated in detail) are of great practical importance. The successive separations of the components of a multiple term are normally proportional to the larger value of J involved; (Landé's interval rule). The factor of proportionality is different for different terms. It increases rapidly with the atomic number Z, and is roughly proportional to Z^2 for similar elements, such as Ca, Sr, Ba. The character of the *Zeeman effect* for any line is completely defined by the numbers R, L, J, for the two levels involved. It is usually possible to work backward from a completely resolved Zeeman pattern and find the nature of the terms involved—a great aid in the analysis of complex spectra.

(f) In the simplest spectra, all the terms for which L is even or odd are themselves even or odd, so that $\Delta L = \pm 1$ for all lines. But in complex spectra all values of L appear among both odd and even terms, and transitions for which $\Delta L = 0$ also give strong multiplets. Transitions for which $\Delta L = \pm 2$, and a few for which it is ± 3, are known, but usually give faint lines. Lines for $\Delta J = \pm 2$ are however extremely rare (except in strong magnetic fields).

(g) In arc spectra—that is, the spectra of neutral atoms—the multiplicities of the various systems are always even if the atomic number is odd, and vice versa, so that odd and even multiplicities *alternate*. The spectrum of a singly ionized atom is similar in general structure to that of the element of next preceding atomic number; of a doubly ionized atom to the element preceding this, and so on (the *displacement law*). In consequence the alternation of odd and even multiplicities is found for successive ionizations of the same element.

(h) The maximum multiplicity in arc spectra is 2 for elements in which there is but one electron outside "completed shells" (Li, Na, K, Rb, Cs; also B, Al, Ga, In, Tl). From these elements it increases by steps of a unit till the "shell" is half completed and then diminishes in the same way—the maximum values being 5 for O, S, Se (Te) and 8 for Mn, (Ma) Re. (Parentheses denote predictions for incompletely analyzed spectra.) In the rare earths it probably rises to 11. When the maximum multiplicity increases with

NORMAL SERIES RELATIONS IN ATOMIC SPECTRA (*continued*)

increasing atomic number the spectroscopic terms have the components with small J-values the lowest. Beyond the maximum they are "inverted" with the large J's low. The higher the maximum multiplicity the greater, generally speaking, is the complexity of the spectrum. The terms of lowest energy are even in all arc spectra except those of B, N, F, and their homologues, and of some of the rare earths.

(i) *Inter-system combinations* between terms of different multiplicities are common when $\Delta R = 2$, and a few are known for which $\Delta R = 4$. They are faint for elements of small atomic number, but often strong when this is large. Deviations from the interval and intensity rules, and the usual rules for the Zeeman effect, also become great in this case. In extreme instances classification by term-types is hardly practicable, though parity and inner-quantum number remain definite.

(j) Arc lines originating in the lowest energy-level in the atom are strong at low temperatures, and usually easily reversed, and are strengthened in the sun-spot spectrum; while those arising from high levels do not reverse, are produced only at higher temperatures, and are little affected, or even weakened, in the spots. The gradation of these properties follows the energy-levels so closely that the temperature classification of the lines ranks with the frequency-differences and the Zeeman effect as a fundamental guide in the interpretation of many-lined spectra.

The *raies ultimes*, which are the last to disappear when the quantity of the element is diminished, are strong lines arising from the lowest level (or occasionally the next).

Resonance lines are those corresponding to the transition from the lowest level to the next lowest with which it can combine. Intersystem combinations, which are usually faint in the arc and spark, very rarely appear as *raies ultimes,* although they are often very strong in the furnace, and important resonance lines.

In spark spectra, lines arising from the lowest levels are strong in the arc, sometimes appear in the furnace, and tend to reverse in the spark, while those from high levels are faint in the arc (if present) and are usually diffuse in the spark.

TABLE 613.—Spectroscopic Notation

Until recently great diversity has prevailed, but an informal committee of American spectroscopists, after extensive correspondence with a large number of workers here and abroad, have suggested a notation[1] which has been generally adopted.

The successive spectra of an element are denoted by Roman numberals, e. g., Ti I, Ti II, Ti III for the spectra of neutral, singly, and doubly ionized titanium. (Lines of Rb IX have been identified.)

The type of term is denoted by letters, corresponding to the quantum numbers L of Hund's theory as follows:

Letter	S	P	D	F	G	H	I	K	L	M
L	0	1	2	3	4	5	6	7	8	9

(Values of L greater than 6 have not yet been met with, but are anticipated among the rare earths.)

The multiplicity is denoted by a superscript at the left 1, 2 . . . . for singlet, doublet terms. The inner quantum number is used as a subscript at the right, and the parity indicated by superscript ° at the right for odd terms . . . . e. g., ${}^4P^{\circ}_{2\frac{1}{2}}$ read "quartet P odd $2\frac{1}{2}$".

[1] Phys. Rev., 33, 900, 1929.

NORMAL SERIES RELATIONS IN ATOMIC SPECTRA (*continued*)

Terms of the same sort are distinguished by prefixing a lower case letter—a^3D, b^3D, etc. Lines are represented as the difference of two terms—the lower one coming first, e.g., $a^3D_2 - y^3F_2^\circ$.

It is recommended that the lowest terms in the spectrum, and others of the same type, multiplicity, and parity be lettered a, b, c—beginning with the lowest. Terms of the opposite parity should be lettered z, y, x—beginning with the lowest. In this way all resonance lines will be designated as $a(\ ) - z(\ )^\circ$.

In most spectra there is a group of low metastable terms of the same parity as the lowest term, separated by a considerable interval from higher terms of the same parity. The letters a, b, c, d should be reserved for the low terms and the high terms should begin uniformly with e.

In a good many spectra, energy levels have been detected whose reality is proved by their combinations, but which can not (at present) be fitted definitely into the scheme of multiple terms. Such levels are to be denoted by Arabic numbers (beginning at the lowest level). It can always be told whether such a level is odd or even, and the inner quantum number can usually, and the multiplicity sometimes be assigned. The corresponding indices are then added to the number, e.g., $^4 23^\circ_{\frac{1}{2}}$.

This notation suffices for the formal description of even the most complex spectra. A further analysis giving the electron configurations responsible for each term should be made so far as possible. Following Hund the individual electrons in an atom may be defined by two quantum numbers, "azimuthal" l and "total" n. The latter is denoted by a numerical prefix, the former by the letters s, p, d, ... as follows:

TABLE 614.—Comparison Azimuthal and Bohr's Quantum Numbers

Letter		s	p	d	f
Azimuthal quantum number	l	0	1	2	3
Bohr's quantum number	k	1	2	3	4

A 6d electron (for example) has $n = 6$, $l = 2$. This is exactly equivalent to Bohr's notation 6_3—the subscript by the value of k. Similarly $4p = 4_2$, $5s = 5_1$. (Note that $n \gtreqless l + 1$.)

The spin of the electron s, being always $\frac{1}{2}$, need not be specified.

The number of electrons of a given type in an atom is represented by an exponent, e.g., $3d^5$.

The quantities s and l are vectors, of the dimensions of angular momentum. By space quantization they combine to give the vectors S, L, and J which define the spectroscopic properties of the energy levels. The multiplicity $R = S + 1$. The details are discussed in Hund's book. The total quantum numbers n are not vectors and do not give a resultant.

A complete specification of an electron configuration would include all the inner electrons—the normal state of iron, for example is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$. For ordinary spectroscopic purposes the complete shells may be omitted, reducing the foregoing to $3d^6 4s^2$. For brevity the total quantum numbers may be omitted when their values are the lowest which the electron can have without belonging to already complete shells. For example, for spectra from K I to Zn I, and Ca II to Ga II, these electrons are 4s, 4p, 3d, 4f. The normal state of Fe I is then represented by $d^6s^2\ ^5D_4$ and that of O II by $s^2p^3\ ^4S_{1\frac{1}{2}}^\bullet$.

Odd and even terms are those in which the sum of the l's for all electrons is odd or even; i.e., in which the number of p or f electrons together is odd or even. Completed shells always give an even sum and may be disregarded.

NORMAL SERIES RELATIONS IN ATOMIC SPECTRA (concluded)

Series of terms arise from configurations in which one electron, keeping the same value of l, has successively higher values of n, the total quantum number. A configuration such as 3d4s4p theoretically belongs therefore to three different series in which either the d, the s, or the p electron takes higher total quantum numbers. In practice this complication is rare as there is almost always one electron which is more easily detached than the others, and is therefore the one to take the higher quantum numbers and give the series. An electron whose total quantum number is higher than those of the electrons discussed in the last section may always be regarded as the most easily detached, as may also one belonging to a group which is not represented in the configurations giving the low terms of the spectrum.

The limiting configuration (i.e., the one obtained by the removal of the electron which takes successively higher values of n to give the series) usually gives multiple terms. Each separate level of these terms is the limit of certain sets of the individual levels of the multiple terms converging to the limit. The configuration of the limit is to be represented as above, followed in parentheses by the notation for the particular type of term which is the limit for the series under consideration, than by the "running" electron, then by the notation for the term (or particular level) given by the whole configuration. For instance the s^2p^3 configuration of O II gives $^4S^\circ$, $^2D^\circ$ and $^2P^\circ$ terms. If we add to this one np electron to get terms of O I the $^4S^\circ$ term gives ^5P and ^3P, the $^2D^\circ$ gives ^3P, ^3D, ^3F, ^1P, ^1D, ^1F and the $^2P^\circ$ gives ^3S, ^3P, ^3D, ^1S, ^1P, ^1D terms. Thus, theoretically, the s^2p^3np configuration gives three ^3P terms, two ^3D terms, two ^1P terms and two ^1D terms. For distinguishing between them it is most convenient to use the notation suggested above. The three P terms would be written $s^2p^3(^4S^\circ)np\,^3P$, $s^2p^3(^2D^\circ)np\,^3P$, and $s^2p^3(^2P^\circ)np\,^3P$.

The notation here described may be considerably simplified for many of the simpler spectra. The abbreviations employed should in all cases be clearly explained by the author.

TABLE 615.—Comparison of Notations

Among the earlier systems of notation which are frequently met with are the following:

Even terms	S	P′	D	F′	G
Odd terms	S′	P	D′	F	G′

Adopted notation	Fowler	Paschen-Götze
$^1S_0$	S	S
$^1P_1$	P	P
$^1D_2$	D	D
$^1F_3$	F	F
$^2S_{\frac{1}{2}}$	σ	s
$^2P_{1\frac{1}{2}}$ $^2P_{\frac{1}{2}}$	π_1 π_2	p_1 p_2
$^2D_{2\frac{1}{2}}$ $^2D_{1\frac{1}{2}}$	δ_1 δ'	d_1 d_2
$^2F_{3\frac{1}{2}}$ $^2F_{2\frac{1}{2}}$	ϕ_1 ϕ'	f_1 f_2
$^3S_1$	S	s
$^3P_2$ $^3P_1$ $^3P_0$	p_1 p_2 p_3	p_1 p_2 p_3
$^3D_3$ $^3D_2$ $^3D_1$	d d′ d″	d_1 d_2 d_3
$^3F_4$ $^3F_3$ $^3F_2$	f f′ f″	f_1 f_2 f_3

As regards the total quantum numbers Fowler usually designates the lowest members of the series by 1s, 1p, 2d, 3f and Paschen-Götze by 1s, 2p, 3d, etc.

The current notation uses Bohr's values which differ from element to element: thus the lowest term in Li is 2^2S, in Na 3^2S, in K 4^2S, in Rb 5^2S, and in Cs 6^2S.

Table 616

ULTIMATE SPECTRUM LINES AND RAIES ULTIMES*

(See p. 508 for explanation.)

(Selected by permission from I. C. T., 5, 322, Meggers.)

A I	6965.43	s_5-p_2
	7067.22	s_5-p_3
	7503.87	s_2-p_1
Ag I	**3280.67**	${}^2S_1-{}^2P_2$
	3382.89	${}^2S_1-{}^2P_1$
Al I	3082.16	${}^2P_1-{}^2D_2$
	3092.72	${}^2P_2-{}^2D_3$
	3092.85	${}^2P_2-{}^2D_2$
	3944.03	${}^2P_1-{}^2S_1$
	3961.54	${}^2P_2-{}^2S_1$
B II	3452.33	—
Ba I	5424.63	${}^3P_2-{}^3D_3$
	5519.11	${}^3P_1-{}^3D_2$
	5535.53	${}^1S_0-{}^1P_1$
	5777.7	${}^3P_0-{}^3D_1$
Ba II	4554.04	${}^2S_1-{}^2P_2$
	4934.09	${}^2S_1-{}^2P_1$
Be I	3321.01	${}^3P_0-{}^3S_1$
	3321.09	${}^3P_1-{}^3S_1$
	3321.35	${}^3P_2-{}^3S_1$
Be II	3130.42	${}^2S_1-{}^2P_2$
	3131.06	${}^2S_1-{}^2P_1$
Bi I	**3067.73**	${}^4S_2-{}^4P_1$
Br II (?)	4704.83	—
	4785.48	—
	4816.72	—
C II	4267.02	${}^2D_2-{}^2F_3$
	4267.27	${}^2D_3-{}^2F_4$
Ca I	**4226.73**	${}^1S_0-{}^1P_1$
	4454.78	${}^3P_0-{}^3D_1$
	4455.88	${}^3P_1-{}^3D_2$
	4456.62	${}^3P_2-{}^3D_3$
Ca II	**3933.67**	${}^2S_1-{}^2P_2$
	3968.48	${}^2S_1-{}^2P_1$
Cb I	**4058.97**	${}^6D_5-{}^6F_6$
	4079.73	${}^6D_4-{}^6F_5$
	4100.97	${}^6D_3-{}^6F_4$
	4123.85	${}^6D_2-{}^6F_3$
	4137.13	${}^6D_1-{}^6F_2$
Cb II	**3094.19**	${}^5F_5-G_6$
	3130.78	${}^5F_4-{}^5G_5$
	3163.37	${}^5F_3-{}^5G_4$
	3194.95	${}^5F_2-{}^5G_3$
	3225.47	${}^5F_1-{}^5G_2$
Cd I	3403.65	${}^3P_0-{}^3D_1$
	3466.20	${}^3P_1-{}^3D_2$
	3610.51	${}^3P_2-{}^3D_3$
Ce II	4012.40	
	4040.76	
	4165.61	
	4186.60	
Cl I	4794.5	
	4810.0	
	4819.4	
Co I	**3453.51**	${}^4F_5-{}^4G_6$
	3465.79	${}^4F_5-{}^4G_6$
	3529.81	${}^4F_4-{}^4G_5$
Cr I	**4254.34**	${}^7S_3-{}^7P_4$
	4274.80	${}^7S_3-{}^7P_3$
	4289.73	${}^7S_3-{}^7P_2$
Cr I	5204.54	${}^5S_2-{}^5P_1$
	5206.04	${}^5S_2-{}^5P_2$
	5208.43	${}^5S_2-{}^5P_3$
Cs I	4555.3	${}^2S_1-{}^2P_2$
	4593.2	${}^2S_1-{}^2P_1$
Cu I	**3247.55**	${}^2S_1-{}^2P_2$
	3273.96	${}^2S_1-{}^2P_1$
Dy I	4000.50	
	4046.00	
	4077.98	
	4167.99	
	4211.74	
Er I	3499.12	
	3692.65	
	3906.34	
Eu I	4129.72	
	4205.03	
F I	6856.01	${}^4P_3-{}^4D_4$
	6902.46	${}^4P_2-{}^4D_3$
Fe I	**3719.94**	${}^5D_4-{}^5F_5$
	3737.14	${}^5D_3-{}^5F_4$
	3745.56	${}^5D_2-{}^5F_3$
	3748.26	${}^5D_1-{}^5F_2$
	3745.90	${}^5D_0-{}^5F_1$
Ga I	4033.01	${}^2P_1-{}^2S_1$
	4172.05	${}^2P_2-{}^2S_1$
Gd I	3646.19	
	3768.40	
Ge I	3039.08	${}^1D_2-{}^1P_1$
	3269.49	${}^1D_2-{}^3P_1$
	4226.61	${}^1S_0-{}^1P_1$
H I	6562.79	$R(\frac{1}{2^2}-\frac{1}{3^2})$
	4861.33	$R(\frac{1}{2^2}-\frac{1}{4^2})$
He I	**3888.64**	${}^3S_1-{}^3P_2$
	5875.63	${}^3P_2-{}^3D_3$
He II	4685.81	$4R(\frac{1}{3^2}-\frac{1}{4^2})$
Hf I	3072.88	
	4093.17	
Hf II	3134.72	
Hg I	3650.15	${}^3P_2-{}^3D_3$
	3654.83	${}^3P_1-{}^3D_2$
	3662.88	${}^3P_0-{}^3D_1$
Ho I	3748.19	
	3891.02	
I I	5161.2	
	5464.6	
In I	4101.76	${}^2P_1-{}^2S_1$
	4511.31	${}^2P_2-{}^2S_1$
Ir I	**3220.79**	
	3437.05	
	3513.67	
K I	4044.16	${}^2S_1-{}^2P_2$
	4047.22	${}^2S_1-{}^2P_1$
Kr I	5570.29	
	5870.92	
La I	5455.11	${}^2D_3-{}^2D'_3$
	5930.59	${}^2D_3-{}^2F_4$
	6249.92	${}^4F_5-{}^4G_6$
La II	**3949.10**	${}^3D_3-{}^3F_4$
	4077.35	${}^3D_1-{}^3F_2$
La II	4123.23	${}^3D_2-{}^3F_3$
Li I	3232.67	${}^2S_1-{}^2P_{1,2}$
	6707.86	${}^2S_1-{}^2P_{1,2}$
Lu I	4518.54	
Lu II	3397.02	
	3472.49	
	3554.43	
Mg I	3829.36	${}^3P_0-{}^3D_1$
	3832.31	${}^3P_1-{}^3D_2$
	3838.29	${}^3P_2-{}^3D_3$
Mn I	**4030.76**	${}^6S_3-{}^6P_4$
	4033.07	${}^6S_3-{}^6P_3$
	4034.49	${}^6S_3-{}^6P_2$
Mo I	**3798.26**	${}^5S_2-{}^5P_3$
	3864.12	${}^5S_2-{}^5P_3$
	3902.96	${}^5S_2-{}^5P_1$
N I	4099.96	${}^2P_1-{}^2D_2$
	4109.94	${}^2P_2-{}^2D_3$
N II	5666.6	${}^3P_1-{}^3D_2$
	5675.9	${}^3P_0-{}^3D_1$
	5679.5	${}^3P_2-{}^3D_3$
N III	4097.3	${}^2P_1-{}^2S_1$
	4103.4	${}^2P_2-{}^2S_1$
Na I	3302.34	${}^2S_1-{}^2P_2$
	3302.94	${}^2S_1-{}^2P_1$
	5889.97	${}^2S_1-{}^2P_2$
	5895.93	${}^2S_1-{}^2P_1$
Nd I	3951.15	
	4177.34	
	4303.61	
Ne I	5400.56	s_4-p_1
	5832.49	s_2-p_1
	6402.25	s_5-p_9
Ni I	3414.77	${}^3D_3-{}^3F_4$
	3492.97	${}^3D_2-{}^3P_1$
	3515.06	${}^3D_2-{}^3F_3$
	3524.54	${}^3D_3-{}^3P_2$
Os I	3262.30	
	3267.94	
	3301.56	
	3752.54	
	3782.20	
Pb I	3639.58	${}^3P_1-{}^3P'_1$
	3683.47	${}^3P_1-{}^3P'_0$
	4057.83	${}^3P_2-{}^3P'_1$
Pd I	3404.59	${}^3D_3-{}^3F_4$
	3421.23	${}^3D_2-{}^3D'_2$
	3516.95	${}^3D_2-{}^3P_1$
	3609.55	${}^3D_2-{}^3F_3$
	3634.68	${}^3D_3-{}^3P_2$
Pr I	4062.83	
	4179.43	
	4189.52	
Pt I	**3064.71**	${}^3D_3-{}^3P_2$
Ra I	**4825.94**	${}^1S_0-{}^1P_1$
Ra II	**3814.44**	${}^2S_1-{}^2P_2$
	4682.20	${}^2S_1-{}^2P_1$
	4201.81	${}^2S_1-{}^2P_2$
Rb I	4215.58	${}^2S_1-{}^2P_1$

* Printed in bold-face type.

ULTIMATE SPECTRUM LINES AND RAIES ULTIMES*

(Selected by permission from I. C. T., 5, 322, Meggers.)

Raies Ultimes.—The strongest lines of any element (the last to disappear when the quantity present is diminished) usually arise from transitions from the lowest level to middle levels of the same multiplicity and belonging to the same family. Among the various lines in a multiplet, that involving the highest inner quantum number is the most persistent; among transitions to terms of the same family, the term of the greatest azimuthal quantum number has the advantage; and the larger multiplicities are preferred to the smaller. In a few cases, the combination of these influences causes a line originating from a level a little above the lowest to be the most persistent of all.

Rh I	3323.10	${}^4F_4-{}^4G_5$
	3396.82	${}^4F_5-{}^4F'_5$
	3434.90	${}^4F_5-{}^4G_6$
	3657.99	${}^4F_4-{}^4D_3$
	3692.35	${}^4F_5-{}^4D_4$
Ru I	3436.74	${}^5F_4-{}^5G_5$
	3498.95	${}^5F_5-{}^5G_6$
	3596.17	${}^5F_3-{}^5G_4$
S I	4694.2	${}^5S_2-{}^5P_3$
	4695.5	${}^5S_2-{}^5P_2$
	4696.3	${}^5S_2-{}^5P_1$
Sa I	4390.87	
	4424.35	
	4434.34	
Sb I	3232.52	${}^2P'_2-{}^2P_1$
	3267.48	${}^2P'_7-{}^2P_1$
Sc I	3907.49	${}^2D_2-{}^2F_3$
	3911.81	${}^2D_3-{}^2F_4$
Sc II	**3613.83**	${}^3D_3-{}^3F_4$
	3630.75	${}^3D_2-{}^3F_3$
	3642.81	${}^3D_1-{}^3F_2$
Se I	**4730.9**	${}^5S_2-{}^5P_3$
	4739.1	${}^5S_2-{}^5P_2$
	4742.3	${}^5S_2-{}^5P_1$
Si I	3905.52	${}^1S_0-{}^1P_1$
Sn I	3009.14	${}^3P_1-{}^3P'_1$
	3034.12	${}^3P_1-{}^3P'_0$
	3175.05	${}^3P_2-{}^3P'_1$
	3262.33	${}^1D_2-{}^1P_1$
	4524.74	${}^1S_0-{}^1P_1$
Sr I	**4607.34**	${}^1S_0-{}^1P_1$
	4832.07	${}^3P_2-{}^3D_3$
	4872.48	${}^3P_1-{}^3D_2$
	4962.25	${}^3P_0-{}^3D_1$
Sr II	**4077.71**	${}^2S_1-{}^2P_2$
	4215.52	${}^2S_1-{}^2P_1$
Ta I	**3311.14**	
	3318.85	
	3406.65	
Tb I	3509.18	
	3561.75	
	3848.76	
	3874.19	
Th I	3538.75	
	3601.05	
	4019.14	
Th II	3290.59	
Ti I	3635.47	${}^3F_2-{}^3G_3$
	3642.68	${}^3F_3-{}^3G_4$
	3653.49	${}^3F_4-{}^3G_5$
	4981.73	${}^5F_5-{}^5G_6$
	4991.07	${}^5F_4-{}^5G_5$
	4999.51	${}^5F_3-{}^5G_4$
	5007.21	${}^5F_2-{}^5G_3$
	5014.25	${}^5F_1-{}^5G_2$
Ti II	**3349.03**	${}^4F_5-{}^4G_6$
	3361.22	${}^4F_4-{}^4G_5$
	3372.80	${}^4F_3-{}^4G_4$
	3383.77	${}^4F_2-{}^4G_3$
Tl I	3775.73	${}^2P_1-{}^2S_1$
	5350.47	${}^2P_2-{}^2S_1$
Tu I	3462.21	
	3761.34	
	3761.91	
U I	3552.20	
	3672.59	
	4241.68	
V I	3183.42	${}^4F_3-{}^4G_4$
	3183.96	${}^4F_4-{}^4G_5$
	3184.00	${}^4F_2-{}^4G_3$
	3185.41	${}^4F_5-{}^4G_6$
V I	3102.30	${}^5F_4-{}^5G_5$
	3110.71	${}^5F_3-{}^5G_4$
	3118.38	${}^5F_2-{}^5G_3$
	3125.29	${}^5F_1-{}^5G_2$
W I	**4008.76**	${}^7S_3-{}^7P_4$
	4294.62	${}^7S_3-X_2$
	4302.12	${}^7S_3-{}^5P_3$
W II	3613.79	
Xe I	4500.98	
	4624.28	
	4671.23	
Yt I	4643.69	${}^2D_2-{}^2F_3$
	4674.84	${}^2D_3-{}^2F_4$
Yt II	**3710.30**	${}^3D_3-{}^3F_4$
	3774.33	${}^3D_2-{}^3F_3$
	3788.69	${}^3D_1-{}^3F_2$
Yb I	3289.37	
	3694.20	
	3988.01	
Zn I	3282.32	${}^3P_0-{}^3D_1$
	3302.6	${}^3P_1-{}^3D_2$
	3344.5	${}^3P_2-{}^3D_3$
Zr I	3519.61	${}^3F_4-{}^3G_5$
	3547.69	${}^3F_3-{}^3G_4$
	3601.19	${}^3F_2-{}^3G_3$
	4687.80	${}^5F_5-{}^5G_6$
	4710.08	${}^5F_4-{}^5G_5$
	4739.48	${}^5F_3-{}^5G_4$
	4772.31	${}^5F_2-{}^5G_3$
	4815.62	${}^5F_1-{}^5G_2$
Zr II	**3391.98**	${}^4F_5-{}^4G_6$
	3438.23	${}^4F_4-{}^4G_5$
	3496.21	${}^4F_3-{}^4G_4$
	3572.47	${}^4F_2-{}^4G_3$

* Printed in bold-face type.

TABLE 617

PERSISTENT LINES, ARC SPECTRA

(Taken from Russell, Astrophys. Journ. 70, 11, 1929.)

The most persistent lines of the ultimate lines. In table 616 only those in visible spectrum are given. Often the most persistent line lies in the ultra-violet. When appearing in Table 616 they are in heavy type.

Wave Lengths in I. A.

H	1215.7	Li	*6707.85	Na	*5895.93	K	7699.01	Rb	7947.64	Cs	8943.46	..	....	$^2S_1$–$^2P_2$
						Ca	*4226.73	Sr	*4607.34	Ba	*5535.53	Ra	4825.9	$^1S_0$–$^1P_1$
						Sc	3911.81	Yt	4102.38	La	....	Ac	....	$^2D_3$–$^2F_4$
						Ti	*3653.49	Zr	*3601.18	Hf	*4093.17†	Th	....	$^3F'_4$–$^3G'_5$
						V	*4379.24	Cb	*4058.99	Ta	....	Pa	....	$^6D_5$–$^6F_6$
						Cr	*4254.34	Mo	*3798.26	W	5053.30‡	U	....	$^7S_3$–$^7P_4$
						Mn	*4030.76	Ma	....	Re	....	..	....	$^6S_3$–$^6P_4$
						Fe	3581.20	Ru	*3498.95	Os	....	..	....	$^5F'_5$–$^5G'_6$
						Co	*3465.80	Rh	*3434.90	Ir	*3220.79§	..	....	$^4F'_5$–$^4G'_6$
						Ni	*3524.54	Pd	*3634.69	Pt	*3064.69	..	....	$^3D_3$–$^3P_2$
						Cu	*3247.55	Ag	*3280.66	Au	*2427.98	..	....	$^2S_1$–$^2P_2$
He	584.4	Be	2348.63	Mg	*2852.11	Zn	*2138.61	Cd	*2288.02	Hg	1849.57	..	....	$^1S_0$–$^1P_1$
					4571.10	..	3075.88	..	*3261.04	..	*2536.52	..	....	$^1S_0$–$^3P_1$
		B	*2497.7	Al	*3961.54	Ga	*4172.06	In	*4511.27	Tl	*5350.46	..	....	$^2P_2$–$^2S_1$
		C	1657.01	Si	2524.12	Ge	2709.63	Sn	*2863.32	Pb	2833.07	..	....	$^3P_1$–$^3P'_1$
		..	1658.13	..	*2528.52	..	2754.59	..	3175.04	..	*4057.83	..	....	$^3P_2$–$^3P'_1$
		N	1200.7	P	1787.5	As	1972.0	Sb	*2311.50	Bi	*3067.69	..	....	$^4S'_2$–$^4P'_1$
		O	1302.25	S	1807.4	Se	1960.2	Te	2142.7	Po	....	..	....	$^3P_2$–$^3S_1$
		F	954.7	Cl	1347.2	Br	1488.6	I	1642.5	..	....	..	....	$^2P_2$–$^2P'_2$
		Ne	735.8	A	1048.3	Kr	1164.9	Xe	1295.7	Rn	....	..	....	$^1S_0$–$^1P_1$

* Recorded by De Gramont (C. R., 171, 1105, 1920) or Meggers and Kiess (Journ. Opt. Soc. Amer., 12, 417, 1926) as *raies ultimes*, which actually have been observed to persist in the manner supposed.

† Spectroscopic classification unknown (Meggers, Bur. Standards Journ. Research, 1, 187, 1928).

‡ $^5D_1$—$^5P_1$. Excitation potential, 0.206 volts.

§ Spectroscopic classification unknown.

TABLE 618
PERSISTENT LINES, SPARK SPECTRA

(Taken from Russell, Astrophys. Journ., 70, 11, 1929.)

Wave Lengths in I. A.

He^+	303.8	Be^+	*3130.42	Mg^+	*2795.52	Ca^+	*3933.66	Sr^+	*4077.71	Ba^+	*4554.04	Ra^+	3814.43	$^2S_1$–$^2P_2$
						Sc^+	*3613.84	Yt^+	*3710.30	La^+	*3949.10	Ac^+	....	$^3D_3$–$^3F_4$
						Ti^+	*3383.76	Zr^+	*3391.96	Hf^+	*2773.37†	Th^+	....	$^4F_5$–$^4G_6$
						V^+	*3093.10	Cb^+	*3094.20	Ta^+	....	Pa^+	....	$^5F_5$–$^5G_6$
						Cr^+	*2835.64	Mo^+	*2816.16	W^+	....	U^+	....	$^6D_5$–$^6F_6$
						Mn^+	*2576.12	Ma^+	....	Re^+	....		....	$^7S_3$–$^7P_4$
						Fe^+	*2382.04	Ru^+	....	Os^+	....		....	$^6D_5$–$^6F_6$
						Co^+	*2378.62	Rh^+	....	Ir^+	....		....	$^5F_5$–$^5G_6$
						Ni^+	2216.47	Pd^+	2296.53	Pt^+	....		....	$^4F_5$–$^4G_6$
						Cu^+	2247.00	Ag^+	*2437.81	Au^+	2082.06		....	$^3D_3$–$^3P_2$
						Zn^+	2061.96	Cd^+	*2265.04	Hg^+	1942.3		....	$^2S_1$–$^2P_2$
Li^+	(192)‡	B^+	1362.46	Al^+	1670.98	Ga^+	1414.4	In^+	1586.4	Tl^+	1321.8		....	$^1S_0$–$^1P_1$
		C^+	858.56	Si^+	1533.55	Ge^+	1649.27	Sn^+	1900.05	Pb^+	*2203.5		....	$^2P_2$–$^2S_1$
		N^+	1085.70	P^+	1542.29	As^+	....	Sb^+	....	Bi^+	....		....	$^3P'_2$–$^3D'_3$
		O^+	834.46	S^+	1259.53	Se^+	....	Te^+	....	Po^+	....		....	$^4S'_2$–$^4P'_3$
		F^+	606.81	Cl^+	1071.03	Br^+	....	I^+	....	..	....		....	$^3P'_2$–$^3P_3$
		Ne^+	460.72	A^+	919.69	Kr^+	886.29	Xe^+	....	Rn^+	....		....	$^2P_2$–$^2P'_2$
		Na^+	376.34	K^+	612.61	Rb^+	....	Cs^+	....	..	....		....	$^1S_0$–$^1P_1$

* Recorded by De Gramont (C. R., 171, 1105, 1920) or Meggers and Kiess (Journ. Opt. Soc. Amer., 12, 417, 1926) as *raies ultimes*, which actually have been observed to persist in the manner supposed.

† See note for *Hf* in Table 617.

‡ Not yet observed; estimated by extrapolation of series.

TABLE 619.—Resonance Lines

(LaPorte, Meggers, Journ. Opt. Soc. Amer., 11, 462, 1925.)

An electron jump which involves the lowest term and gives rise to the line of greatest wave length, i. e., the first transition which is connected with emission and requires the least energy for excitation, in spectra where there is no metastable level lying close to the lowest term gives a resonance line.

Z	Element	Arc		Spark	
		Terms	λ	Terms	λ
19	K	$^2S_1-{}^2P_2$	7664.94		
37	Rb		7800.20		
20	Ca	$^1S_0-{}^3P_1$	6572.78	$^2S_1-{}^2P_2$	3933.66
38	Sr		6892.62		4077.71
21	Sc	$(^2D_3-{}^4F_4)$	>6413	$^3D_3-{}^3F_4$	3613.86
39	Y		>6933		3710.30
22	Ti	$^3F_4-{}^5G_5$	6295.30	$^4F_5-{}^4G_6$	3349.41
40	Zr		?		3391.96
23	V	$^4F_5-{}^6D_4,\ {}^6G_6$?	5632.47	$^5F_5-{}^5G_6$	3093.10
41	Cb		?		3094.20
24	Cr	$^7S_3-{}^7P_4$	4254.34	$^6D_5-{}^6F_6$	2835.64
42	Mo		3798.26		2816.16
25	Mn	$^6S_3-{}^8P_4$	5394.68	$^7S_3-{}^7P_4$	2576.12
43	...		...		...
26	Fe	$^5D_4-{}^7\overline{D}_5,\ {}^7F_5$	5166.29; 4375.93	$^6D_5-{}^6F_6$	2382.04
44	Ru		?		?
27	Co	$^4F_5-{}^6\overline{F}_6,\ {}^6G_6$	?	$(^5F_5-{}^5G_6)$	2388.93
45	Rh		?		?
28	Ni	$(^3F_4-{}^5\overline{F}_5,\ {}^5G_5)$	?	$(^4F_5-{}^4G_6)$	2416 16
46	Pd		?		?

TABLE 620.—Electron Impacts in Gases

(Langmuir, Jones, Rev. Mod. Phys., 2, 233, 1930.)

Probabilities that an electron, while going through gas at 1 mm pressure, 20°C, will collide inelastically, P_k, elastically, P_e, so as to produce 1st excited state, P_r, or so as to ionize P_i.

Gas	Volts	P_k	P_e	P_r	P_i	Gas	Volts	P_k	P_e	P_r	P_i
He	50	7.7	2.1	2.8	0.9	Hg	30	48.0	33.3	17.3	13.6
	100	6.0	1.5	.7	1.6		50	49.1	29.5	14.7	19.9
Ne	75	9.3	1.1	1.5	1.8		100	50.3	25.9	16.7	21.7
	100	9.2	.9	1.3	2.4		250	32.0	21.3	6.7	20.4
A	30	19.1	24.1	5.9	4.7	H	100	9.2	5.3	3.5	3.9
	50	18.4	20.8	1.9	9.5		250	7.2	6.3	2.1	3.6
	100	18.7	14.5	1.7	11.4	N	75	20.2	14.9	5.3	9.3
	150	18.4	12.8	2.7	11.4		100	16.2	10.4	4.8	10.3

TABLE 621.—Average Life for Various Quantum States of Excited Atoms

Theoretical values of ionized helium (Maxwell, Sugiura, Stack.)

Levels	Average Life T(n, l,) (sec.)	Mean av. life T(n), (sec.)
$2_0, 2_1$	———— 1.02×10^{-10}	1.36×10^{-10}
$3_0, 3_1, 3_2$	1.01×10^{-8}, 3.38×10^{-10}, 9.93×10^{-10}	6.4 "
$4_0, 4_2, 4_2, 4_3$	1.46 " , 7.89 " , 2.32×10^{-9}, 4.66×10^{-9}	2.13×10^{-9}
$5_0, 5_1, 5_2, 5_3, 5_4$	2.2 " , 1.49×10^{-9}, 4.33×10^{-9}, 8.73×10^{-9}, 1.45×10^{-8}	5.4×10^{-9}
$6_0, 6_1, 6_2, 6_3$, —, 6_5	3.3 " , 2.44 " , 7.20 " , 1.47×10^{-8}, —, 3.91 "	1.18×10^{-8}
$7_0, 7_1, 7_2, 7_3$, —, 7_6	5.0 " , 3.65 " , 1.18×10^{-9}, 2.4×10^{-8}, —, 8.80 "	2.24×10^{-8}

The values for H are 16 × those for He (Sugiura, 1927, 1929). It is to be noted that the average life is longer for progressively higher quantum states.

Maxwell 1931 obtains $1.1 \pm 0.2 \times 10^{-8}$ sec. for av. life 6th quantum state (cf. 1.18×10^{-8}) given above. Maxwell's qualitative observation on first four lines of 4686 He + series, 4 > 3, 5 > 3, 6 > 3, 7 > 3, show definitely the longer life for higher quantum states.

Poole (Phys. Rev., 33, 22, 1929) metastable Hg atom (Z^3P_0), max. time 4.2×10^4 sec. (6.8 mm).

See Ann. Phys., 83, 294, 1927, for early summary, including following:

O spark, 467, 459μμ, 1.53×10^{-8} sec. Ca spark 3933A, 3968A, 0.65×10^{-8} sec.
O arc, 6158, 4368A, 14.9 " Ca arc 4226A, 3.4 "

Koenig, Ellett. (Phys. Rev., 39, 576, 1932) give for 2^3P_1 state Cd, 2.5×10^{-6} sec.

MOLECULAR CONSTANTS OF DIATOMIC MOLECULES

(From manuscript by E. D. McAlister, 1932.)

Energy levels for molecules can be evaluated from their spectra, just as for atoms. *Widely spaced levels* in molecules correspond roughly to those known for atoms, are similarly designated (see "Notation for Spectra of Diatomic Molecules," R. S. Mulliken, Phys. Rev., 36, 611, 1930) and are said to be related to the *electronic* configuration. A *system* of bands arise from transitions from one (often multiple) electronic configuration to another.

Diatomic molecules have two other sets of levels in addition to the electronic. One is due to the energy of mutual *vibration* of the two nuclei and the other to the energy of rotation of the molecule as a whole. A distinct set of vibrational levels is associated with each electronic state. The energy difference corresponding to each level of such a set from that of the associated electronic state is obtained (approximately) by giving successive positive integral values to n in the expression $n(\omega_0 - \omega_0 \times n + \ldots)$; x a positive constant. The frequency of vibration (ω) is obtained by differentiating this with respect to n; $\omega = \omega_0(1 - 2xn + \ldots)$. At the lowest level where the amplitude and energy of vibration are vanishingly small, $n = 0$ and $\omega = \omega_0$. A transition from one vibrational level to another gives rise to a *single band.*

A distinct set of rotational levels is associated with each vibrational level. The presence of large numbers of these closely spaced rotational levels gives rise to the many individual lines of the band. The rotational energy, relative to the associated vibrational level is given (approximately) by $Bm^2(1 - m^2u^2 + \ldots)$; where $u = \frac{2B_0}{\omega_0}$ and m is a parameter which is zero for zero rotation. Usually $BI = h/8\pi^2c = 27.70 \times 10^{-40}$ g. cm, where I = moment of inertia of the molecule about an axis through its center of mass and perpendicular to the line joining its nuclei. For multiple levels this relation is not accurately true. I varies with the vibrational energy, and becomes I_0 when it is *zero;* the corresponding nuclear separation is $\gamma_0 = \sqrt{I_0/\mu}$ where $\mu = \frac{m_0 m_1 m_2}{(m_1 + m_2)}$. m_0 = mass of an atom of unit atomic weight $= 1.650 \times 10^{-24}$ g. m_1, m_2 are the atomic weights of the two atoms composing the molecule.

The heat of dissociation is $D^v = \int_0^{n_0} \omega dn$, where n_0 is the value of n for $\omega = 0$. If the bands can be experimentally followed to $\omega = 0$, D^v can be determined from spectroscopic data. Usually this cannot be done but Birge and Sponer (Phys. Rev., 28, 259, 1926) have found that, for the normal state of certain types of molecules, fairly trustworthy values of D^v can be obtained by assuming $\omega = \omega_0(1 - 2 \times n)$ throughout the range $n = 0$ to $n = n_0$; then $D = \omega_0^2/4\omega_0 x$. In the accompanying table D is D^v plus the electronic energy for the particular state in question. Each horizontal line in the table is for one electronic state. The second column labelled energy (volts) is the electronic energy above the normal level which is assumed to have zero electronic energy. The heat of dissociation is tabulated in the same units which is the number of volts potential change an electron must undergo in order to acquire the corresponding energy. One electron volt per molecule $= 2.306 \times 10^4$ g − cal.$_{15}$ per g-mole = 8100 cm^{-1} per molecule. The data in the table are taken from compilations by Birge, Nat. Res. Council Bull. 57, "Molecular Spectra in Gases" and Mulliken, Phys. Rev., 32, 206, 1928, and ibid., 33, 738, 1929, and are calculated with the "old mechanics" formulae.

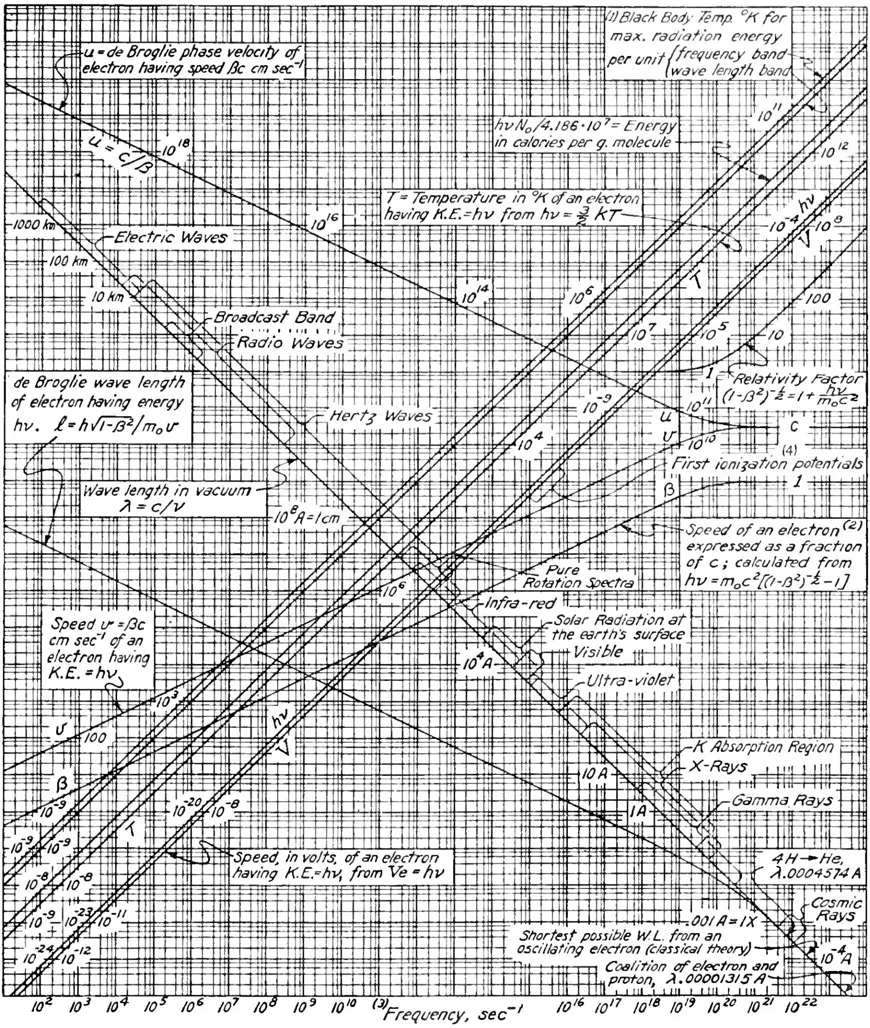
TABLE 623
MOLECULAR CONSTANTS OF DIATOMIC MOLECULES

Molecule	Energy (volts)	γ_0 (cm × 10^8)	I_0 (g cm² × 10^{40})	ω_0 (cm^{-1})	$\omega_0 X$ (cm^{-1})	D^v (volts)	D (volts)	State
Ag H	0	1.630	4.38	(1690)				$^1\Sigma$
	3.69	1.665	4.57	(1490)				$^1\Sigma$
Al H	0	1.658	4.41	(1625)				$^1\Sigma$
	2.90	1.690	4.58	(1082)				$^1\pi$
	5.51	1.65		(1326)				$^1\Sigma$
Au H	0	1.54	3.93	2249.4	34.0	4.59	4.59	$^1\Sigma$
	3.37	1.69	4.74	1630	79	1.04	4.41	$^1\Sigma$
	4.72	1.71		(1548)				$^1\Sigma$
Be F	0			1253	10.2	4.8	4.8	$^2\Sigma$
	4.10			1156	8.4	4.9	9	$^2\pi$
Be H	0	1.35		2026				$^2\Sigma$
	2.48	1.34		2053				$^2\pi$
Be O	0	1.33		1465	12.7	6.4	6.4	$^1\Sigma$
	2.62	1.36		1354	8.9	5.2	7.8	$^1\Sigma$
$B^{11}O$	0	1.21	15.68	1874	11.7	9.3	9.3	$^2\Sigma$
	2.91	1.36	20.03	1249	10.6	4.6	7.5	$^2\pi_i$
	5.30	1.31	18.53	1270	10.1	5.0	10.3	$^2\Sigma$
C_2	0	1.31	17.03	1630	11.7	7.0	7.0	$^3\pi$
	2.39	1.27	15.84	1773	19.4	6.4	8.8	$^3\pi$
Cd H	0	1.776	5.201	(1374)				$^2\Sigma$
	2.75, 2.88	1.674	4.65, 4.59					$^2\pi_n$
C H	0	1.13	1.95	(2806)				$^2\pi_n$
	2.86	1.11	1.90	(2851)				$^2\Delta_i$
	3.18	1.20	2.21	(<2806)				$^2\Sigma$
C N	0	1.17	14.65	2056	13.8	9.5	9.5	$^2\Sigma$
	1.78	1.23		1729	13.5	6.8	8.6	$^2\pi_i$
	3.18	1.15	14.14	2144	21.3	6.7	9.9	$^2\Sigma$
C O	0	1.15	14.9	2155	12.7	11.2	11.2	$^1\Sigma$
	5.98			1725	14.5	6.4	12.4	$^3\pi$
	7.14			1173	9	4.6	11.9	$^3\Sigma$
	7.99	1.24	17.31	1499	17.2	4.0	12.0	$^1\pi$
	10.35			(2214)				$^3\Sigma$
	10.73	1.12	14.26	2132	50	2.8	13.5	$^1\Sigma$
	11.35			(2133)				$^1\Sigma$
	11.46			(2134)				$^1\Sigma$
	12.30			1914	19.8	.6	12.9	$^1\pi$
CO +	14.2	1.11	14.05	2197	15.2	9.8	9.8	$^2\Sigma$
	16.7	1.25	17.7	1550	14.1	7.1	9.6	$^2\pi_i$
	19.8	1.17	15.4	1698	24.3	3.7	9.3	$^2\Sigma$

MOLECULAR CONSTANTS OF DIATOMIC MOLECULES

Molecule	Energy (volts)	γ_0 (cm × 10^8)	I_0 (g cm² × 10^{40})	ω_0 (cm⁻¹)	$\omega_0 X$ (cm⁻¹)	D^v (volts)	D (volts)	State
Cu H	0	1.471	3.544	1903.7	37.36	3.02	3.02	$^1\Sigma$
	2.88	1.582	4.097	1655.7	44.63	1.89	4.77	$^1\Sigma$
	5.51	1.50						$^1\pi$
H_2	0	.76	.480	4262	113.5	4.42	4.42	$^1\Sigma$
	11.12	1.55	1.99	1325	15.9			$^1\Sigma$
	11.70	.97	.78	2390	73			$^3\pi$
He_2	0							$^1\Sigma$
	20.3	1.052	3.650	(1731.8)				$^1\Sigma$
	20.6	1.047	3.62	(1790.1)				$^1\Sigma$
	20.9	1.071	3.784					$^1\pi$
Hg H	0	1.763	5.143	1308	104	.369	.369	$^2\Sigma$
	3.08 3.56	1.593	4.22 4.18	2025.7 (1938.7)	43.8	2.90	6.46	$^2\pi_n$
	4.18	2.02		(1940)				$^2\Sigma$
Mg H	0	1.74	4.86	1462.2	31.25	2.12	2.12	$^2\Sigma$
	2.38	1.70	4.62	1568.7	34.75	2.18	4.56	$^2\pi_n$
	5.09	1.70		(1622)				$^2\pi$
N_2	0			2345	14.4	11.7	11.7	$^1\Sigma$
	8.18			1446	13.9	3.7	11.9	$^3\Sigma$
	8.50			1679	13.8	5.7	14.2	$^1\pi$
	9.35	1.21	16.98	1718	14.4	5.3	14.6	$^3\pi_n$
	13.00	1.15	15.24	2019	26.0	1.6	14.6	$^3\pi_n$
N_2^+	16.9	1.12	14.41	2187	16.3	9.1	9.1	$^2\Sigma$
	20.1	1.08	13.35	2392	22.8	8	11	$^2\Sigma$
NH	0	1.08	1.81					$^3\Sigma$
	3.67	1.08+						$^3\pi$
NO	0	1.15	16.29	1892	14.4	7.9	7.9	$^2\pi_n$
	5.45	1.07	14.05	2352	13	14	19	$^2\Sigma$
	5.60	1.42	24.80	1030	7.5	4.4	10	$^2\pi_n$
	6.45			(2347)				$^2\Sigma$
	6.58			2324	27	6.2	13	
NO^+	9.4							$^1\Sigma$
	21							$^3\Sigma$
	22							π(?)
O_2	0	1.21	19.2	1565	11.4	5.1	5.1	$^3\Sigma$
	1.62	1.23	19.8	1415	11.9			$^1\Sigma$
	6.09	1.61	34.22	708	12.4			$^3\Sigma$
O_2^+	13.5			1926	16.5	6.9	6.9	$^2\pi_n$
	18.7			855	13.7			$^2\pi_n$
	18.7			1026	11.1			π(?)
	20.8			1180	17.8			Σ(?)
O H	0	.979	1.500	(3568.4)		5.4	5.4	$^2\pi_i$
	4.00	1.022	1.634	3084.7	97.8	3.0	7.0	$^2\Sigma$
Zn H	0	1.608	4.234	(1552)				$^2\Sigma$
	2.87	1.522	3.78					$^2\pi_n$

VARIOUS ATOMIC AND SPECTRUM FUNCTIONS



1. In black body unpolarized radiation the energy transmitted per sec per sq cm per unit solid angle per unit frequency band is, by Planck's radiation formula, $K_\nu = (h\nu^3/c^2)/(e^{h\nu/kT}-1)$; per unit wave-length band it is $E_\lambda = (hc^2/\lambda^5)/(e^{hc/\lambda kT}-1)$. The values $h\nu/kT = 2.82144 \equiv a$ and $hc/\lambda kT = 4.96511 \equiv b$ make K_ν and E_λ take their maximum values, whence the temperature of the radiation that has its maximum K_ν or E_λ at a particular frequency or wave length can easily be computed.

2. Electron speed $\div 1846^{1/2}$ = speed of a proton having the same energy, with negligible error at low energies. This holds to within 0.1% up to $\nu = 3\times10^{17}$, but becomes 1.8% low at $\nu = 3\times10^{18}$, 12% low at $\nu = 3\times10^{19}$, and should not be used at all for higher frequencies. For convenience, $.6968 \div 1846^{1/2} = .01622$; $20.89 \div 1846^{1/2} = .4863$; $66.07 \div 1846^{1/2} = 1.538$; $.2203 \div 1846^{1/2} = .005129$

3. Frequency is used as the fundamental quantity with Birge's values (Physical Review Supplement 1, 1, July 1929) of the physical constants, and the final calculation rounded off to four figures.

Speed of light, $c = 2.99796 \times 10^{10}$ cm sec⁻¹
Electronic charge, $e = 4.770 \times 10^{-10}$ abs esu
Electronic mass (by deflection), $m_0 = 8.994 \times 10^{-28}$ g
Planck's constant, $h = 6.547 \times 10^{-27}$ erg sec
Molecular gas constant, $k = 1.3708_9 \times 10^{-16}$ erg deg⁻¹
299.796 abs volts = 1 abs esu of potential
1 15° calorie, $J_{15} = 4.1852$ abs joules
Avogadro's number, $N_0 = 6.064 \times 10^{23}$ mole⁻¹
Atomic weight of helium = 4.0022
Atomic weight of hydrogen = 1.00777

4. Corresponding to "first ionization potentials," Cs 3.88 V, He 24.48 V.

Compiled by W. Edwards Deming
Drawn by Mrs. C. Sherry
Revised, August 1929

U. S. Department of Agriculture
Bureau of Chemistry & Soils
Washington, D. C.

RADIOACTIVITY

INTRODUCTION. THE URANIUM FAMILY

(References: Kovarik, McKeehan, Nat. Res. Council, Bull. 51 (reprint 1929); Andrade, Structure of the atom, 3rd ed., 1926; Rutherford, Radiations from radioactive substances, 1930; Kohlrausch, Radioactivität, 1929; Radioactive constants of 1930, Report International Radium-Standards Commission, Rev. Mod. Phys., 3, 427, 1931.)

Certain elements (about 40) of high atomic weight (also slightly K and Rb) are unstable in that they spontaneously change to elements of lower atomic weight with the production of heat and the emission of α, β, or γ rays. Radioactivity is an additive property of the atom, dependent only on the particular element and not on the chemical compound into which this element enters nor on the physical conditions controlling ordinary reactions—temperature, whether solid, gaseous or liquid, etc. The lives of these elements vary from 10^{10} yrs. to 10^{-11} sec. (See Table 625.)

TABLE 625.—The Uranium Family, T, λ, τ

At. Wt. = atomic weight; P. No. = proton number; At. No. = atomic number; yr = years; d = days; h = hours; m = minutes; s = seconds; T = half-period; τ = average life; λ = decay constant.

		T	λ	τ	Rays and end product
Uranium I	UI At. Wt. 238.14 At. No. 92 P. No. 238	$4.4 \cdot 10^9$yr $1.4 \cdot 10^{17}$s	$1.6 \cdot 10^{-10}$yr^{-1} $5.0 \cdot 10^{-18}$s^{-1}	$6.3 \cdot 10^9$yr $2.0 \cdot 10^{17}$s	α, UX_1
Uranium X_1	UX_1 At. No. 90 P. No. 234	24.5d $2.12 \cdot 10^6$s 23.8d $2.06 \cdot 10^6$s	$2.83 \cdot 10^{-2}$d^{-1} $3.28 \cdot 10^{-7}$s^{-1} $2.90 \cdot 10^{-2}$d^{-1} $3.37 \cdot 10^{-7}$s^{-1}	35.4d $3.05 \cdot 10^6$s 34.4d* $2.97 \cdot 10^6$s*	β, UX_2 .9965 UZ .0035
Uranium X_2 (Brevium) ca 99.65%	UX_2 At. Wt. — At. No. 91 P. No. 234	1.14m 68.4s	0.61m^{-1} $1.01 \cdot 10^{-2}$s^{-1}	1.64m 98.7s	β, UII
Uranium Z ca 0.35%	UZ At. No. 91 P. No. 234	6.7h $2.4 \cdot 10^4$s	0.103h^{-1} $2.87 \cdot 10^{-5}$s^{-1}	9.7h $3.5 \cdot 10^4$s	β, UII
Uranium II	UII At. No. 92 P. No. 234	$3 \cdot 10^5$yr $9.4 \cdot 10^{12}$s	$2.3 \cdot 10^{-6}$yr^{-1} $7.4 \cdot 10^{-14}$s^{-1}	$4.3 \cdot 10^5$yr $1.4 \cdot 10^{13}$s	α, Io .970 UY .030
Uranium Y ca 3%	UY At. No. 90 P. No. 231 or 230	24.6h 1.03d $8.88 \cdot 10^4$s	$2.82 \cdot 10^{-2}$h^{-1} 0.675d^{-1} $7.81 \cdot 10^{-6}$s^{-1}	35.5h 1.48d $1.28 \cdot 10^5$s	β, Ac.

* Earlier values still in use.

Notes on Decay Constants: For U_1 the calculation is based on Z = no. of α particles from 1 g Ra per sec. = 3.70×10^{10}; Ra/U = 3.40×10^{-7}; Avogadro's No. = 6.064×10^{23}; no account is taken of the branching Ac series. The values given are for T and τ, upper, for λ lower limits.

For UX_1, the lowest value T = 23.8 is mentioned as well as the one preferred by the Commission.

UII. The adoption of 3×10^5 yr. is recommended.

ThC′. Mme. Curie has recently calculated λ = about 10^9sec^{-1}. (Geiger-Nuttal Law). In view of the uncertainty of the values, $T < 10^{-6}$ sec. has been proposed.

AcC″. 150 curves give T = 4.71 min., 9, T = 4.76 min. Both values are given.

Table 626

RADIOACTIVITY

IONIUM—RADIUM FAMILY T, λ, τ

(Taken from 1930 Report International Radium Standards Commission, Rev. Mod. Phys., 3, 427, 1931.)

		T	λ	τ	Rays and end product
Ionium	Io At. No. 90 P. No. 230	$8.3\cdot10^{4}$yr $2.6\cdot10^{12}$s	$8.3\cdot10^{-6}$yr^{-1} $2.6\cdot10^{-13}$s^{-1}	$1.2\cdot10^{5}$yr $3.8\cdot10^{12}$s	α, Ra
Radium	Ra At. No. 88 P. No. 226	1590 yr $5.02\cdot10^{10}$s	$4.36\cdot10^{-4}$yr^{-1} $1.38\cdot10^{-11}$s^{-1}	2295 yr $7.24\cdot10^{10}$s	α, Rn
Radon	Rn At. No. 86 P. No. 222	3.825d $3{,}305\cdot10^{5}$s 3.823d $3.303\cdot10^{5}$s	0.1812d^{-1} $2.097\cdot10^{-6}$s^{-1} 0.1813d^{-1} $2.098\cdot10^{6}$s^{-1}	5.518d* $4.768\cdot10^{5}$s* 5.515d* $4.765\cdot10^{5}$s*	α, RaA
Radium A	RaA At. No. 84 P. No. 218	3.05m 183s	0.227m^{-1} $3.78\cdot10^{-3}$s^{-1}	4.40m 264s	α, RaB
Radium B	RaB At. No. 82 P. No. 214	26.8m $1.61\cdot10^{3}$s	$2.59\cdot10^{-2}$n^{-1} $4.31\cdot10^{-4}$s^{-1}	38.7m $2.32\cdot10^{3}$s	β, RaC
Radium C	RaC At. No. 83 P. No. 214	19.7m $1.18\cdot10^{3}$s	$3.51\cdot10^{-2}$m^{-1} $5.86\cdot10^{-4}$s^{-1}	28.5m $1.17\cdot10^{3}$s	β, α, .9996 RaC′ .0004 RaC″
Radium C′ 99.96% (99.97%)	RaC′ At. No. 84 P. No. 214	ca10^{-6}s	10^{6}s^{-1}	10^{-6}s	α, RaD
Radium C″ 0.04% (0.03%)	RaC″ At. No. 81 P. No. 210	1.32m 79.2s	0.525m^{-1} $8.7\cdot10^{-3}$s^{-1}	1.9m 115s	β, RaD
Radium D	RaD At. No. 82 P. No. 210	22yr $6.94\cdot10^{8}$s	0.0315yr^{-1} $1.00\cdot10^{-9}$s^{-1}	31.7yr $1.00\cdot10^{9}$s	β, RaE
Radium E	RaE At. No. 83 P. No. 210	4.9d $4.26\cdot10^{5}$s 5.0d $4.32\cdot10^{5}$s	0.141d^{-1} $1.63\cdot10^{-6}$s^{-1} 0.139d^{-1} $1.61\cdot10^{-6}$s^{-1}	7.07d* $6.13\cdot10^{5}$s* 7.2d* $6.22\cdot10^{5}$s*	β, RaF
Radium F Polonium	RaF(Po) At. No. 84 P. No. 210	140d $1.21\cdot10^{7}$s	$4.95\cdot10^{-3}$d^{-1} $5.73\cdot10^{-8}$s^{-1}	202d $1.75\cdot10^{7}$s	α, RaG
Radium G (Uranium lead)	RaG At. Wt. 206.016 At. No. 82 P. No. 206				

* Earlier values still in use.

TABLE 627
RADIOACTIVITY
ACTINIUM FAMILY

(Taken from 1930 Report International Radium Standards Commission, Rev. Mod. Phys., 3, 427, 1931.)

		T	λ	τ	Rays and end product
Actinium Uranium Uranium Y (see Uranium Family)	AcU	ca 10^8 to 10^9yr			
Protactinium	Pa At. No. 91 P. No. 231	$3.2 \cdot 10^4$yr $1.01 \cdot 10^{12}$s	$2.17 \cdot 10^{-5}$yr^{-1} $6.86 \cdot 10^{-13}$s^{-1}	$4.6 \cdot 10^4$yr $1.46 \cdot 10^{12}$s	α, Ac
Actinium	Ac At. No. 89 P. No. 227	13.5yr $4.23 \cdot 10^8$s 20yr $6.3 \cdot 10^8$s	$5.15 \cdot 10^{-2}$yr^{-1} $1.63 \cdot 10^{-9}$s^{-1} $3.4 \cdot 10^{-2}$yr^{-1} $1.1 \cdot 10^{-9}$s^{-1}	19.4yr $6.12 \cdot 10^8$s 29yr* $9.2 \cdot 10^8$s*	β, RaAc
Radio-actinium	RaAc At. No. 90 P. No. 227	18.9d $1.63 \cdot 10^6$s	$3.66 \cdot 10^{-2}$d^{-1} $4.24 \cdot 10^{-7}$s^{-1}	27.3d $2.36 \cdot 10^6$s	α, AcX
Actinium X	AcX At. No. 88 P. No. 223	11.2d $9.7 \cdot 10^5$s 11.4d $9.85 \cdot 10^5$s	$6.17 \cdot 10^{-2}$d^{-1} $7.14 \cdot 10^{-7}$s^{-1} $6.08 \cdot 10^{-2}$d^{-1} $7.06 \cdot 10^{-7}$s^{-1}	16.2d* $1.40 \cdot 10^6$s* 16.4d* $1.42 \cdot 10^6$s*	α, An
Actinon	An At. No. 86 P. No. 219	3.92s	0.177s^{-1}	5.66s	α, AcA
Actinium A	AcA At. No. 84 P. No. 215	$2 \cdot 10^{-3}$s	374s^{-1}	$2.88 \cdot 10^{-3}$s	α, AcB
Actinium B	AcB At. No. 82 P. No. 211	36.0m $2.16 \cdot 10^3$s	$1.93 \cdot 10^{-2}$m^{-1} $3.21 \cdot 10^{-4}$s^{-1}	51.9m $3.12 \cdot 10^3$s	β, AcC
Actinium C	AcC At. No. 83 P. No. 211	2.16m 130s	0.321m^{-1} $5.35 \cdot 10^{-3}$s^{-1}	3.12m 187s	α, β, .9984 AcC″ .0016 AcC′
Actinium C′ 0.32%	AcC′ At. No. 84 P. No. 211	ca$5 \cdot 10^{-3}$s	ca140s^{-1}	ca$7 \cdot 10^{-3}$s	α, AcD
Actinium C″ 99.68%	AcC″ At. No. 81 P. No. 207	4.76m 286s 4.71m 283s	0.145m^{-1} $2.43 \cdot 10^{-3}$s^{-1} 0.146m^{-1} $2.44 \cdot 10^{-3}$s^{-1}	6.87m* 412s* 6.83m* 410s	β, AcD
Actinium D Actinium Lead Pb207	AcD At. Wt. 207.016 (?) At. No. 82 P. No. 207				

* Earlier values still in use.

Table 628

THORIUM FAMILY: POTASSIUM, RUBIDIUM

		T	λ	τ	Rays and end product
Thorium	Th At. Wt. 232.12 At. No. 90 P. No. 232	$1.8 \cdot 10^{10}$yr $5.6 \cdot 10^{17}$s	$4.0 \cdot 10^{-11}$yr^{-1} $1.2 \cdot 10^{-18}$s^{-1}	$2.5 \cdot 10^{10}$yr $8.0 \cdot 10^{17}$s	α, $MsTh_1$
Mesothorium 1	$MsTh_1$ At. No. 88 P. No. 228	6.7yr $2.1 \cdot 10^{8}$s	0.103yr^{-1} $3.26 \cdot 10^{-9}$s^{-1}	9.7yr $3.05 \cdot 10^{8}$s	β, $MsTh_2$
Mesothorium 2	$MsTh_2$ At. No. 89 P. No. 228	6.13h $2.21 \cdot 10^{4}$s	0.113h^{-1} $3.14 \cdot 10^{-5}$s^{-1}	8.84h $3.18 \cdot 10^{4}$s	β, RdTh
Radiothorium	RdTh At. No. 90 P. No. 228	1.90yr $6.0 \cdot 10^{7}$s	0.365yr^{-1} $1.16 \cdot 10^{-8}$s^{-1}	2.74yr $8.65 \cdot 10^{7}$s	α, ThX
Thorium X	ThX At. No. 88 P. No. 224	3.64d $3.14 \cdot 10^{5}$s	0.190d^{-1} $2.20 \cdot 10^{-6}$s^{-1}	5.25d $4.54 \cdot 10^{5}$s	α, Tn
Thoron	Tn At. No. 86 P. No. 220	54.5s	$1.27 \cdot 10^{-2}$s^{-1}	78.7s	α, ThA
Thorium A	ThA At. No. 84 P. No. 216	0.14s	4.95s^{-1}	0.20s	α, ThB
Thorium B	ThB At. No. 82 P. No. 212	10.6h $3.82 \cdot 10^{4}$s	$6.54 \cdot 10^{-2}$h^{-1} $1.82 \cdot 10^{-5}$s^{-1}	15.3h $5.51 \cdot 10^{4}$s	β, ThC
Thorium C	ThC At. No. 83 P. No. 212	60.5m $3.63 \cdot 10^{3}$s	$1.15 \cdot 10^{-2}$m^{-1} $1.91 \cdot 10^{-4}$s^{-1}	87.3m $5.24 \cdot 10^{3}$s	β, α, .65ThC′ .35ThC″
Thorium C′ 65% 65.7%	ThC′ At. No. 84 P. No. 212	10^{-9}s(?) $< 10^{-6}$s	10^{9}s^{-1}(?) $> 10^{6}$s^{-1}	10^{-9}s(?) $< 10^{-6}$s	α, ThD
Thorium C″ 35% 34.3%	ThC″ At. No. 81 P. No. 208	3.1m 186s	$2.24 \cdot 10^{-1}$m^{-1} $3.73 \cdot 10^{-3}$s^{-1}	4.47m 286.3s	β, ThD
Thorium D Thorium lead Pb208	ThD At. Wt. 208.016 (?) At. No. 82 P. No. 208				

Potassium (K19) and rubidium (Rb37) emit β rays; the β-ray activity of rubidium is 1/15 that of uranium; T is about 10^{11} years. Cesium (55Ce) has been found to have an activity less than 1/90 of potassium. Hoffman considers neither sodium nor cesium radioactive. Be, av. period 10^{14} years, (Langer, Raitt, 1933).

Note—The following data is from Holmes, Lawson, Nature, 117, 620, 1926:

	Ur	Th	K	Rb
N, atoms per g	....	....	15.5×10^{21}	7.09×10^{21}
T, half-value period, years	....	....	15×10^{11}	1×10^{11}
λ, disintegration constant, years^{-1}	....	....	4.6×10^{-13}	69×10^{-13}
No. atoms disintegrating per years, $n\lambda$	....	....	7.1×10^{9}	49×10^{9}
Kinetic energy, E ergs per β ray	....	....	7.30×10^{-7}	2.04×10^{-7}
Energy per g, per year, $nE/(4.19 \times 10^{7})$ cal	(7900×10^{-4})	(2300×10^{-4})	1.24×10^{-4}	2.38×10^{-4}

Table 629

RADIOACTIVITY UNITS

(Taken from 1930 Report International Radium Standards Commission, Rev. Mod. Phys., 3, 427, 1931.)

Radium content is expressed in g or mg of radium, regardless of its chemical combination. It is always desirable to know the total weight and nature of the compound.

Radon (radium emanation).—A curie: Quantity of Rn in equilibrium with 1 g Ra. One curie Rn has a vol. 0.66 mm^3 at 0° C 760 mm. One curie (Rn without decay products) can with complete utilization of the α-particles keep by its ionization of air a saturation current of 2.75×10^6 e.s.u. (0.92 milliampere).

Sub-units: Millicurie, microcurie, milli-microcurie (10^{-9}).

Eman. $= 10^{-10}$ curie per l (10^{-13} curie/cm^3)—*concentration* unit used for Rn content of the atmosphere.

Mache Unit (M. E.): Concentration unit referred to the Rn content of 1 l, = quantity Rn/l which without decay products and with complete utilization of the α particles can maintain by its ionization of air a saturation current of 10^{-3} e.s.u. One M. E. corresponds to 3.64×10^{-10} curie/liter = 3.64 eman.

It is recommended that the curie be extended to include the equilibrium of any decay product of radium, specifying the element as 1 curie Rn. The unit quantity of any radioactive element may be expressed in terms of the mass equivalent to 1 g Ra with respect to the effect of the rays as to the number of atoms decaying per sec., e.g., 1 mg Ra equivalent is that amount of an element whose number of atoms decaying per sec. equals that of 1 mg Ra (3.7×10^7 atoms/sec.).

Polonium.—"1 curie Po" = amount equiv. to 1 g Ra emitting 3.7×10^{10} α particles per sec. = quantity in radioactive equilibrium with 1 g Ra $= 2.24 \times 10^{-4}$ g Po.

That quantity of Po whose α radiation directed to one side only is fully utilized to ionize air and which can support a current of 1 e.s.u. corresponds to 1.68×10^{-10} g Po or 0.75×10^{-6} curie Po. 1 curie Po would, in the utilization of its rays in all directions, support a saturation current in air of 2.66×10^{-6} e.s.u., 1 microcurie (one-sided radiation) = 1.33 e.s.u.

Mesothorium.—"1 mg MsTh" usually signifies that γ-ray equivalent of 1 mg Ra-RaC, compared after absorption by 5 mm of lead. (This definition is inexact and open to criticism.)

All determinations of content of Ra, Ru, Ms, Th, Po, etc., must be dated. (Condensed from Report of the International Radium Standards Commission, Rev. Mod. Phys., 1931.)

TABLE 630.—Miscellaneous Radioactivity Constants

(Recommended by International Radium Standards Commission, 1930, Rev. Mod. Phys., 1931.)

$m_0c^2 = 5.9303 \times 10^{-3}$, α particles. m_0, α particle $= 6.598 \times 10^{-24}$ g.
$m_0c^2/2e = 6.2162 \times 10^6$, α particles.
$m_0c^2 = 8.1207 \times 10^{-7}$, β particles. m_0, electron $= 9.040 \times 10^{-28}$ g.
for $e/m_0 = 5.276_3 \times 10^{17}$ e.s.u./g. for β particle.
$m_0c^2/e = 1.7034 \times 10^3$, for ditto.

Kinetic energy $= E = m_0C^2(\eta - 1) = 5.9303 \times 10^{-3}(\eta - 1)$ erg. for α particles

$\beta =$ velocity particle/velocity light; $\eta = (1-\beta^2)^{-\frac{1}{2}}$, $m = m_0\eta$.
$E = 8.1252 \times 10^{-7}(\eta - 1)$ erg, β particles.
$E = 5.9303 \times 10^{-3}(\eta - 1)$ erg, α particles.

Velocity in equivalent volts, p $= 299.80E/2e = 3.1426 \times 10^{11}E$, α particles.
$= 299.80E/e = 6.2851 \times 10^{11}E$, β particles.

Product of magnetic field strength $\times$ radius of curvature of the path:

$\log R = (m_0c^2/2e)\eta\beta = 6.2162 \times 10^6\eta\beta$, α particles.
$= (m_0c^2/e)\eta\beta = 1.7034 \times 10^3\eta\beta$, β particles.
$\lambda = hc/E = 1.9628 \times 10^{16}/E$ for $h = 6.547 \times 10^{-27}$ erg.sec.
$1.9637 \times 10^{16}/E$ for $h = 6.55 \times 10^{-27}$ erg.sec.
$Z =$ no. α particles emitted per sec. from one g Radium $= 3.7 \times 10^{10}$.

(The chief source of error lies in the Ra equivalent of the preparation (e.g., RaC). This arises from the decay-curve of RaB-RaC. Moreover in washing with alcohol to remove residual radon, RaB is dissolved in excess of RaC. The error causes a minimal value of Z.)

Ratio Ra/U in old unaltered minerals $= 3.4 \times 10^{-7}$; U/Ra $= 2.94 \times 10^6$.

Basic values for calculation of number of ion pairs produced by one α particle:

$k = k_0R^{\frac{2}{3}}$ and velocity from $v^3 = a_0R_0$ (all data 0° C, 760 mm).
As basis for $k_0 = Zk = 8.18 \times 10^{15}$ (Meyer-Schweidler, 1927)
and $Z = 3.7 \times 10^{10}$
For RaC′ $R_0 = 6.58$ cm
$k = 8.18 \times 10^{15}/3.7 \times 10^{10} = k_0 \times 6.58^{\frac{2}{3}}$, $k_0 = 6.296 \times 10^4$.
Recommended value: $k_0 = 6.3 \times 10^4$.

For a_0, different values are obtained according to the choice of RaC′, ThC′ or Po as reference. This may mean that $v^3 = aR$ is not exact and that the definition of the range as the intercept of the descending line of the Bragg curve with the abscissa has no theoretical basis.

	R_0	v	a_0	$a_0^{\frac{1}{3}}$
RaC′	$R_0 = 6.58$	$v = 1.022 \times 10^9$	$a_0 = 1.0790 \times 10^{27}$	$a_0^{\frac{1}{3}} = 1.026 \times 10^9$
TnC′	8.168	2.054 "	1.0609 "	1.020 "
Po	3.67	1.593 "	1.1015 "	1.032 "
In use	6.60	1.922 "	1.0758 "	1.0246 "
Recommended			1.08 "	1.026 "

TABLE 631.—Relative Phosphorescence Excited by Radium

(Becquerel, C. R. 129, 912, 1899.)

Without screen,	Hexagonal zinc blende	13.36	With screen	.04
" "	Pt. cyanide of barium	1.99	" "	.05
" "	Diamond	1.14	" "	.01
" "	Double sulphate Ur and K	1.00	" "	.31
" "	Calcium fluoride	.30	" "	.02

The screen of black paper absorbed most of the α rays to which the phosphorescence was greatly due. For the last column the intensity without screen was taken as unity. The γ rays have very little effect.

TABLE 632.—Vapor Pressure of the Radium Emanation in cm of Mercury

(Rutherford and Ramsay, Philos. Mag. 17, 723, 1909, Gray and Ramsay, Trans. Chem. Soc. 95, 1073, 1909.)

Temperature C°	−127°	−101°	−65°	−56°	−10°	+17°	+49°	+73°	+100°	+104° (crit.)
Vapor Pressure	0.9	5	76	100	500	1000	2000	3000	4500	4745

TABLE 633

RADIOACTIVITY

α Particles: Range, Velocity, Ionization

RaC′ (84 RaII) taken as standard: $V_{std} = 1.922 \times 10^9$ cm/sec.

(Table taken from Report International Radium Standards Commission, 1930, Rev. Mod. Phys., 1931.)

As an α particle passes through matter, energy is dissipated, principally in ionization; its velocity diminishes. Ultimately the α particle can not be detected. Rutherford was able to detect by their scintillations, α particles of velociy 0.15 V_s and Blackett in his study of cloud-tracks of RaC′ α rays found tracks corresponding to a velocity greater than 0.04V_s. When the kinetic energy becomes equal to that of an electron fallen a p.d. of 13.5 volts, then an α particle should not produce even a single pair of ions.

When α particles encounter successive thin layers nearly the same number emerge as enter up to a certain thickness. Beyond, the number transmitted decreases rapidly with small increments in the thickness. If the ionization in a thin layer of gas at increasing distance is plotted against distance, the decrease from max. ionization is rapid, the ionization descending nearly to zero along a steeply sloping line, becoming asymptotic to the distance axis. Marsden-Perkins have defined the range as the abscissa of the point where the straight line portion of the curve, produced, intersects the distance axis.

For the discussion of ranges see especially Rosenblum, C. R., 190, 1124, 1930, and Rutherford, Chadwick, Ellis, "Radiations from Radioactive Substances," 1930, pages 82 et seq. and 86. For two decimal places the relation $v^3 = aR$ gives sufficient accuracy for normal ranges. The basic value for ion production of α particles is that for RaC′; $K = 2.2 \times 10^5$. For the velocity of α particles from ThC, Rutherford, Chadwick, Ellis chose 1.701, while Mmes. Curie and Joliet-Curie propose 1.698×10^9 cm/sec.

Ranges, Velocities and Ion Productions

In the Table for R, v, k (range, velocity, ion production) the directly observed values are denoted by +. The calculation of the other values for v and k was made by using the basic values denoted ++.

RANGES AT 0° C AND 760 MM HG IN AIR (R_0); AT 15° C (R_{15}). VELOCITY (v) AND ION PRODUCTION (k)

	Ranges at 0°	Ranges at 15°	Velocity	Ion production
UI	2.53	2.67	$1.40 \cdot 10^9$	$1.16 \cdot 10^5$
	2.59	2.73	1.41	(1.18)
UII	2.96	3.12	1.47	1.29⁺
	3.11	3.28	1.50	(1.33)
Io	3.03	3.19	1.48	1.31
Ra	3.21	3.39	1.51	1.36⁺
Rn	3.91	4.12	1.61	1.55
RaA	4.48	4.72	1.69	1.70
RaC	3.9	4.1	1.61	1.55
RaC′	6.600⁺⁺	6.96	1.922⁺⁺	2.20⁺⁺
	(6.58)	(6.94)		
Po	3.67	3.87	1.593⁺ (1.58)	1.49
	(3.72)	(3.92)	(1.59)	(1.50)
Pa	3.48	3.67	1.55	1.44
RdAc	4.43	4.68	1.68	1.69
	and 4.77	4.34	1.64	1.67
AcX	4.14	4.37	1.65	1.61
An	5.49	5.79	1.81	1.95
AcA	6.24	6.58	1.89	2.12
AcC	5.22	5.51	1.78	1.88
	and 4.82	5.09	1.73	1.79
AcC′	(6.2)?	(6.5)?	(1.9)?	ca 2
Th	2.5	2.6	1.39	1.15
RdTh	3.81	4.02	1.60	1.53
ThX	4.13	4.35	1.64	1.61
Tn	4.80	5.06	1.73	1.78
ThA	5.39	5.68	1.80	1.92
ThC	4.53	4.78	(1.698)	1.71
	4.47	4.72	(1.703) 1.701⁺	1.70
ThC′	8.17	8.62	2.052⁺	2.54

RADIOACTIVITY. α PARTICLES

TABLE 634.—Relative Ranges of α Particles of RaF in Gases

All values are at n. t. p.; the accepted value for the α particle in air is 3.721 cm and the following values are merely relative. (After van der Merwe.)

Gas	Air	H_2	H_2O	CH_4	N_2	CO	O_2	N_2O_3	CO_2	SO_2	CH_3Br
Range, cm	3.58	16.28	....	3.96	3.62	3.51	3.32	3.26	2.36	1.97	1.76
Molec. stopping power	1.00	.22	.77	.91	.99	1.02	1.08	1.11	1.52	1.82	2.04

TABLE 635.—Relative Ranges of α Particles of RaC′ in Solid Elements

(After Rausch von Traubenberg.)

Element	Li	Mg	Al	Ca	Fe	Ni	Cu	Zn	Ag	Cd	Sn	Pt	Au	Tl	Pb
cm $\times 10^{-3}$	12.9	5.8	4.1	7.9	1.9	1.8	1.8	2.3	1.9	2.4	2.9	1.3	1.4	2.3	2.4

TABLE 635 (*a*).—Long-Range α Particles. Relative Numbers

Scintillations at abnormally great distances from thorium active deposit were first observed by Rutherford-Wood. The range in air of the particles producing these was 11.3 cm and it was shown by Rutherford that their mass was that of helium atoms, i. e., that they were α particles. It now appears certain that some of the particles of long range must have been H nuclei from Hydrogen or its compounds or protons from artificial disintegration.

RaC′ (84 RaII) Range	7.0 cm, 1 000 000	9.3 cm, 20	11.2 cm, 70
ThC′ (84 ThII)	8.6 cm, 1 000 000	9.5 cm, 70	11.5 cm, 200

TABLE 636.—Atomic Stopping Powers, *S*, for α Particles of RaC′, *Z*, Atomic Number

(After Rausch von Traubenberg.)

The ability of atoms and molecules to stop α particles or, more briefly, their stopping power, was first investigated by Bragg, and, more recently, by others. The atomic stopping power for elements may be given by the formula $S = R_0\rho_0A/R\rho A_0$, where R_0, ρ_0, A_0 are the range, density and atomic weight for the standard and R, ρ, A, the corresponding quantities for the element considered. The stopping power therefore varies inversely as the range and the density but directly as the atomic weight.

	Z	S	$SZ^{-2/3}$		Z	S	$SZ^{-2/3}$		Z	S	$SZ^{-2/3}$
H	1	0.200	0.20	Si	14	1.23	0.21	Ag	47	2.74	0.21
He	2	.380	.24	Cl	17	1.76	.27	Cd	48	2.75	.21
Li	3	.519	.25	A	18	1.80	.26	Sn	50	2.86	.21
Be	4	.750	.30	Ca	20	1.69	.23	I	53	3.55	.25
C	6	.864	.28	Fe	26	1.96	.22	Pt	78	3.64	.20
N	7	.939	.26	Ni	28	1.89	.21	Au	79	3.73	.20
O	8	1.00	.25	Cu	29	2.00	.21	Tl	81	3.76	.20
Mg	12	1.23	.24	Zn	30	2.05	.21	Pb	82	3.86	.21
Al	13	1.27	.23	Br	35	2.51	.23				

TABLE 637.—Atomic Stopping Powers of Molecules for the α Particles of RaC′ (84RaII) Relative to that of the Oxygen Atom

(After Rausch von Traubenberg, Philipp.)

Molecule	CO	CO_2	CH_3Br	CH_3I	Cl_2	HCl	NH_3	H_2O (liquid)
Stopping power	1.85	2.78	3.93	4.97	3.51	1.92	1.46	1.53

TABLE 638

RADIOACTIVITY

H PARTICLES

Marsden first observed the long-range particles due to the impact of α particles on matter, now known to be H particles, i.e., hydrogen nuclei or protons set in motion by α rays. Rutherford made a thorough study of this phenomenon, measured the ranges in H_2 of H particles due to α particles of various speeds, counted the relative number of α and H particles by the scintillation method; measured the magnetic and electrostatic deflection of the H particles and proved them to be hydrogen nuclei (protons) in motion. He was able to produce them by bombardment of substances rich in H_2. When the α particles have a 7 cm air range, the H particles have a maximum air range of 29 cm.

H Particles from Atomic Nuclei Bombarded by α Particles from RaC′

(Taken from Kovarik, McKeehan, Nat. Res. Council Bull. 51, 1925.)

RANGES IN CM IN AIR AT 15° C IN DIRECTIONS INCLINED TO THE α RAYS

At. No.	Nucleus Symbol	At. Wt.	Inclination 0°	90°	180°	Ref., Remarks
3	Li	6, 7		10		1, (2, doubtful)
4	Be	9		18		1, (2, doubtful)
5	B	10, 11	58		38	3
6	C	12		6		1, (2, none)
7	N	14	40		18	3
9	Fl	19	65		48	3
10	Ne	20, 22		16		2, very few
11	Na	23	58		36	3
12	Mg	24, 25, 26		13 (18–30)		1, (2, very few)
13	Al	27	90		67	4
14	Si	28, 29, 30		12 (18–30)		1, (2, very few)
15	P	31	65		49	3
16	S	32		18–30		2, very few
17	Cl	35, 37, 39		18–30		2, very few
18	A	36, 40		18–30		2, very few
19	K	39, 41		18–30		2, very few

[1] Kirsch-Pettersson, 1924. [2] Rutherford-Chadwick, 1924. [3] Rutherford-Chadwick, 1922.
[4] Rutherford-Chadwick, 1921.

RADIOACTIVITY

TABLE 639.—Relative Total Ionization by α Rays in Various Gases

(After Bragg, Taylor, Laby, Hess-Hornyak.)

Gas	Mean relative total ionization	Gas	Mean relative total ionization	Gas	Mean relatiue total ionization
Air	100	C_2H_4	122	CH_4	117.3
H_2	99.5	C_2H_6	130	CH_4O	122
N_2	96.3	C_5H_{12}	134.8	C_2H_2	126.5
O_2	112	C_2H_6O	123	CH_3I	133
CO	101.5	$C_4H_{10}O$	132.3	C_2H_5I	128
CO_2	107	C_6H_6	129	$CHCl_3$	129
NH_3	90	C_2H_4O	105	C_2H_5Cl	129.5
N_2O	102	HBr	129	CCl_4	132
CS_2	137.5	HI	129	CH_3Br	132
SO_2	103	HCl	129		

TABLE 640.—Delta Rays

Delta rays are electronic rays (β rays) produced by bombarding a substance with α particles, an ionization of a comparatively infrequent type. δ rays are of various velocities, some corresponding to a few volts; others have a velocity, 3×10^9 cm/sec. (2400 volts); the number of δ rays produced by bombarding metals is of the order of 8 to 10 per α particle.

The existence of swift δ rays in hydrogen gas has been proved by Bumstead (cloud-track method). From the wide column of droplets (α-ray track) there are short, narrow tracks nearly at right angles. Wilson obtained similar δ-ray tracks in air near the beginning of the α-ray tracks. These experiments show that some δ rays are capable of ionizing air along a path of considerable length. Bianu (ionization method) was able to show that δ rays ionize the gas and determined the velocity of the swiftest δ rays as 2.9×10^9 cm/sec. This velocity corresponds to 2400 volts. C. T. R. Wilson suggests that the δ rays may be due to expulsion of electrons from inner orbits of the bombarded atoms, which would agree with Kapitza's observation that the average energy lost by an α particle in producing a pair of ions is greater at high velocities than at low. Bianu shows that the number of low-speed δ rays produced is 40 times as great as the number of high-speed δ rays and that each α ray from RaF produces, on the average, 10 of the more numerous class. His work also shows the δ-ray emission to be independent of the nature of the metal bombarded, an observation in agreement with earlier investigations. The usual explanation offered for the production of δ rays is that an α particle entering a substance loses energy in ionization and that some of the electrons liberated possess speeds which enable them to escape.

TABLE 641.—Heating Effect of Radium and Its Emanation

(Rutherford and Robinson, Philosophical Magazine, 25, p. 312, 1913.)

	Heating effect in gram-calories per hour per gram radium.			
	α rays.	β rays.	γ rays.	Total.
Radium	25.1	–	–	25.1
Emanation . . .	28.6	–	–	28.6
Radium A . . .	30.5	–	–	30.5
Radium B + C . .	39.4	4.7	6.4	50.5
Totals	123.6	4.7	6.4	134.7

Other determinations: Hess, Wien. Ber. 121, p. 1, 1912, Radium (alone) 25 2 cal. per hour per gram. Meyer and Hess, Wien. Ber. 121, p. 603, 1912, Radium in equilibrium, 132.3 gram. cal. per hour per gram. See also, Callendar, Phys. Soc. Proceed. 23, p. 1, 1910; Schweidler and Hess, Ion. 1, p. 161, 1909; Ångström, Phys. ZS. 6, 685, 1905, etc.

TABLE 642

RADIOACTIVITY

BETA RAYS

β rays are negatively charged particles (electrons) of the same nature as other electrons. It seems settled that the β particle is emitted first; the γ ray is emitted from the atom resulting after the disintegration of the nucleus caused by the emission of the β particle. In emitting β rays (random in direction) the original element is shifted one place to a next higher atomic number. Therefore one emitted electron is nuclear. Recent work proves some to be extra-nuclear. The velocity of the β particles is such that it is necessary in dealing with them to consider the Lorentz-Einstein equation, $m = m_0\ (1 - \beta^2)^{-1/2}$; m_0 being the mass of a very slowly moving electron, β, the ratio of the velocity of the particle to that of light, V_0.

The β and γ rays are best designated by their spectra. A complete compilation of these would be beyond the scope of these tables. See Kovarik and McKeehan, Nat. Res. Council, Bull. 51, 1929; or Rutherford, Chadwick, Ellis, radiations from radioactive substances.

The absorption coefficients (μ) are not precisely defined by the relation $I = I_0\ e^{-\mu x}$, but they are of great value in practical work and for the rapid diagnosis of a radioactive substance. It appears desirable to include them and to give also the limits of velocity of the β-ray spectra.

Substance	Type of decay	μ cm^{-1} Al	μ/ρ	D cm Al	Magnetic spectrum velocity limits in 10^{10} cm/sec.	Remarks *	Accompanying γ rays
UX_1	β	460	170	0.0015	1.44–1.74	3L, 1B	No nuclear
UX_2	β	18	6.75	.038	2.46–2.88	2B	Weak nuclear
UZ	β	270	100	.0026	?	?	?
		to	to	to			
		36	13.5	.019			
Ra	α	312	116	.00222	1.56–2.04	3L	1 nuclear line
RaB	β	890	330	.00078	1.08–2.47	31L	9 nuclear lines
		80	29.5	.0087			
		13	4.84	.053			
RaC + C″	$\alpha + \beta$	50	18.5	.0139	1.14–2.96	63L	11 nuclear lines
		13	4.84	.053			
RaD	β	5500	2037	.000126	.96–1.20	5L	1 nuclear line
RaE	β	45.5	16.9	.0152	2.05–2.84	1B	Weak nuclear
UY	β	ca 300	110	.0023	?	?	?
Pa	α	126	47	.0055	1.47–2.35	12L	3 nuclear lines
Ac	β	?	?	?	?		
RdAc	α	175	65	.004	.66–2.3	49L	10 lines
AcX	α	?	?	?	.88–2.22	21L	5 lines
AcB	β	ca 1000	370	.0007	1.49	1L?	
AcC + C″	$\alpha + \beta$	29	10.7	.024	2.25–2.56	8L	3 nuclear lines
$MsTh_1$	β	?	?	?	?	?	?
$MsTh_2$	β	40	14.8	.018	1.09–2.90	31L	8 lines
		to	to	to			
		20	7.4	.034			
RdTh	α	420	150	.0017	1.19–1.53	6L	2 lines
ThB	β	153	57	.0045	1.88–2.99	5L	2 nuclear lines
ThC	$\alpha + \beta$	14.4	5.35	.048			
ThC″	β	21.6	8.0	.032	.91–2.87	37L	11 nuclear lines
K	β	74	27.4	.0094			Weak
		49	18	.014			
Rb	β	700	260	.001			
		190	70	.0037			
		900	333	.0077			

* B = band, L = line. Bands originate in the primary (nuclear) rays; lines in the photo-electrons of the gamma rays.

μ/ρ is the mass absorption coefficient (ρ = density); D is the thickness in which the radiation is reduced to half value and $= 0.69315\mu$. All data refer to aluminum as the absorbing material.

Table 643

RADIOACTIVITY

WORK OF EXTRACTION OF BETA PARTICLES

(After Bohr-Coster. Taken from Kovarik, McKeehan, Nat. Res. Council Bull. 51, 1929.)

Works of extraction V_i in volts $\times 10^5$; $V_i = E(T/R)$; they have been interpolated assuming linear-variation of $(T/R)^{\frac{1}{2}}$ with z in values given. In computing V_i, $\log_{10} E = 6.13129 - 10$; values not depending on interpolation italicized. M values, average of M_I and M_V; to get M_I add, M_V, subtract correction term. Similarly with N, mean of N_I and N_{VII}; O, mean of O_I and O_V.

Atomic No.	Levels K	L_I	L_{II}	L_{III}	M	N	O
92	*1.1469*	*0.2169*	*0.2088*	*0.1711*	*0.0453 ± 100*	*0.0090 ± 54*	*0.0022 ± 14*
91	1.1195	0.2106	0.2025	0.1666	0.0438 ± 96	0.0086 ± 52	
90	*1.0922*	*0.2043*	*0.1964*	*0.1624*	*0.0424 ± 93*	*0.0082 ± 50*	
89	1.0636	0.1981	0.1905	0.1582	0.0410 ± 90	0.0078 ± 48	
88	1.0353	0.1921	0.1846	0.1540	0.0396 ± 86	0.0074 ± 47	
87	1.0073	0.1862	0.1789	0.1499	0.0382 ± 83	0.0071 ± 45	
86	0.9797	0.1804	0.1733	0.1458	0.0368 ± 80	0.0067 ± 44	
85	0.9525	0.1746	0.1677	0.1418	0.0354 ± 77	0.0064 ± 42	
84	0.9257	0.1690	0.1622	0.1378	0.0342 ± 74	0.0060 ± 41	
83	*0.8993*	*0.1634*	*0.1569*	*0.1339*	*0.0330 ± 70*	*0.0057 ± 39*	
82	*0.8744*	*0.1582*	*0.1518*	*0.1330*	*0.0316 ± 68*	*0.0052 ± 37*	*0.0008 ± 6*
81	*0.8509*	*0.1532*	*0.1467*	*0.1263*	*0.0305 ± 66*	*0.0049 ± 36*	*0.0008 ± 6*
80	*0.8275*	*0.1481*	*0.1419*	*0.1226*	*0.0293 ± 63*	*0.0046 ± 35*	
79	*0.8037*	*0.1434*	*0.1372*	*0.1189*	*0.0282 ± 60*	*0.0043 ± 34*	*0.0006 ± 5*
78	*0.7798*	*0.1389*	*0.1324*	*0.1153*	*0.0270 ± 58*	*0.0039 ± 32*	*0.0006 ± 5*

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TABLE 644.—Effective Range of Beta Particles from RaE in a Few Elements

(After Gray-Douglas. Taken from Kovarik, McKeehan, Nat. Res. Council Bull. 51, 1929.)

Element	C	Al	Cu	Sn	Pb
Effective range, g/cm^2..........	.474	.460	.432	.395	.354

TABLE 645.—Absorption of Characteristic Beta Particles in Air and CO_2

(After Kovarik.)

Source	Air μcm^{-1}	Air $(\mu/\rho)cm^2/g$	CO_2 μcm^{-1}	CO_2 $(\mu/\rho)cm^2/g$
UX_1	0.12	100	0.23	126.
UX_2	0.0065	5.43	0.0114	6.26
UX_1 } UX_2	0.0047	(Friman)		
RaD	0.097	81	0.183	101.
	0.64	535	1.69	930.
RaE	0.0152	12.70	0.0297	16.31
AcB	0.31	260		
AcC } AcC″	0.0091	7.60	0.0175	9.62
ThB	0.090	75	0.142	78.
ThC } ThC″	0.0068	5.68	0.0129	7.08

Table 646

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GAMMA RAYS

γ rays are extremely penetrating, nondeviable by electric and magnetic fields, produce ionization of gases, act on the photographic plate, excite phosphorescence. Like X rays, they are similar to light. γ rays are merely X rays produced in the radioactive atoms. The reflection of X rays and γ rays from crystals leaves no doubt that the wave theory of light is applicable. There are to be solved the same problems, as indicated by Bragg for the corpuscular theory of X rays. The same difficulties exist as in the case of visible radiation. Theoretical investigations on γ rays, based on the electromagnetic theory, lead to conclusions not very different from those of a corpuscular theory.

Emission of gamma rays.—The number of γ rays per sec. from RaB and RaC in equilibrium with 1 g of Ra, is 1.43×10^{10} and 1.49×10^{10} (Hess-Lawson). The mean value obtained by Kovarik for the number of γ rays per sec. from Ra(B + C) in equilibrium with 1 g of Ra was 7.28×10^{10}, which is nearly (within 2%) one γ ray per atom disintegrating. The random emission in time of penetrating γ rays from radium has been proved.

Energy and wave length of gamma rays.—The energies and wave lengths of γ rays have been obtained variously; much further research is required. The direct experimental determination of γ-ray wave lengths by reflection from a crystal (NaCl) was first made by Rutherford-Andrade for the γ rays of RaB and RaC. Both surface planes and internal planes were utilized. They showed that certain strong lines of the RaB γ-ray spectrum are identical with characteristic X rays (L series) of nonradioactive lead. The shortest wave length measured was that of a γ ray of RaC reflected at a grazing angle of 44′ having a wave length of about 70 X.U. (1 X.U. $= 10^{-11}$ cm $= 10^{-3}$ A.U.). The counting method was applied by Kovarik to high frequency γ rays of RaC reflected from calcite. The shortest measured wave length was about 28 X.U.

The determination of γ-ray wave lengths from mass absorption is made on the supposition that the relation between mass absorption and wave length found for X rays may be applied to γ rays. For X rays, outside regions of selective absorption, $\mu/\rho = k\lambda^n$ where λ is the wave length and n has a value 2.5 to 3. Rutherford found that as the mass absorption coefficient, μ/ρ, of γ rays approaches the order of magnitude of the mass scattering coefficient τ/ρ, it varies more slowly with λ, probably as the first power; from his X-ray data he concluded that the very penetrating γ rays have most probably a wave length between 20 and 7 X.U. Minna Lang applied her work on the absorption of hard X rays to the γ rays of all known radio-elements and found that many are probably characteristic X rays (K, L, and M series).

The energies of γ rays have been obtained also by measuring the energy of β rays "excited" by them in various elements. The velocity of the β particles emitted by the γ rays from the atom of any element depends upon the frequency of the γ rays and upon the work necessary to separate the emitted electron from the rest of the atom. The photoelectric equation $E = h\nu - W$, is applicable. (E is the energy of the "excited" β ray measured outside the atom, ν is the frequency of the exciting γ rays and W is the work of separation.) The energy E is the value of Hr in magnetic deflection experiments, the work W, the energy corresponding to the appropriate absorption edge in the X-ray spectrum of the atom in the electronic structure of which the β ray arises. The work of separation W will have different values for different energy levels in the same atom and different values for the same energy level in different atoms. The soft γ rays of RaB are the L-series X rays of Pb. Some of the γ rays of radio-elements belong to the K, L, M, or other series of X rays of the atoms concerned in the β-ray disintegration considered. Evidently, some of the γ rays are of extra-nuclear source. The most penetrating γ rays can not be so accounted for and must therefore be of nuclear origin.

Connection between gamma rays and beta rays (or alpha rays).—The more recent work has established: (1) some of the β rays are of photoelectric origin (extranuclear) "excited" by the γ rays; (2) some of the γ rays originate in rearrangements of electrons in the same part of the atom (ordinary X-ray types); (3) the change in nuclear charge requires some β rays in disintegration to be of nuclear origin; (4) some of the γ rays, all of the very penetrating rays, are of nuclear origin. The principal point in dispute is whether emission of nuclear β rays precedes or follows the emission of nuclear γ rays.

TABLE 647
RADIOACTIVITY
GAMMA RAYS

Nuclear analysis.—Analysis of nuclear γ rays show evidence for energy levels in the nucleus analogous to those in the extra-nuclear structure as found by X-ray analysis. When instability arises in the nucleus an electron occupying a level of higher energy falls to a level of less energy, the excess energy being emitted as a γ ray; since several changes of this kind are possible, γ rays of several different but definite frequencies may be emitted from this nucleus; further, different groups of frequencies may be emitted from different individual nuclei. Some of the γ rays cause (photo-electric) emission of electrons from various extra-nuclear levels, thus producing the β-ray lines in the β-ray spectrum, and rearrangement of the extra-nuclear electrons produces the γ rays which correspond in frequency to characteristic X rays. The nuclear electron finally arrives in a stationary state in which it is not permanently stable and it flies out from the nucleus. The nuclear electrons, one per atom disintegrating, thus leave the atom with different energies and form the continuous β-ray spectrum.

The absorption of γ rays by gases has not been studied at all exhaustively. Chadwick investigated the absorption of the γ rays from radium, i.e., from RaC, in air and in CO_2 by varying the gas pressure, and in air by varying the distance from the source. Hess made measurements in air by varying the distance. Chadwick's value for μ in air, reduced to atmospheric pressure and 15° C, is 6.0×10^{-5}/cm and Hess' value is 4.47×10^{-5} cm.

Ahmad and Ahmad-Stoner find that the absorption coefficient per atom can be expressed as the sum of two terms, $aZ + bZ^4$, which corresponds to a similar expression for the absorption of X rays, $aZ + \beta\lambda^3Z^4$, the first term representing scattering and the second term true absorption.

Ionization by gamma rays.—With the development of the theory of atomic structure by study of X rays and γ rays, of ionizing potentials, and by applications of the quantum theory, views on ionization by γ rays have become more definite. When an X ray or a γ ray traverses matter its energy $h\nu$ may be absorbed ($h\nu = E + W$), an electron requiring energy W to remove it from the atom being ejected with residual kinetic energy E. Such an electron has generally been called a secondary β ray. It in turn may react with another atom, losing energy equivalent at least to the ionizing potential of a particular energy level in the atom ionized, repeating the process until its energy is dissipated, and leaving electrons and positive ions in its trail. Each of the ejected tertiary electrons if possessing sufficient energy, loses energy in the same manner.

Moseley-Robinson's values for the total number of pairs of ions produced per sec. in air at n.p.t. by γ rays from quantities of RaB and RaC in equilibrium with 1 g of Ra are 0.84×10^{14} and 11.34×10^{14}, respectively. From Chadwick's value for the coefficient of absorption in air the mean "range" is $1/\mu = 1.6 \times 10^4$ cm. This gives as a mean value 7.5×10^{10} pairs of ions/sec./cm of path in air for all the penetrating γ rays from 1 g of radium in equilibrium, and, taking one γ ray per atom of RaB and RaC disintegrating (Kovarik), this means about one pair of ions per cm of path in air for each penetrating γ ray.

RADIOACTIVITY

GAMMA RAYS

It is evident from the quantum relation, $h\nu = E + W$, that γ rays of given frequency will cause the emission of β particles of definite velocities, one for each energy level that can be ionized, from an atom of a given element (including all its isotopes). This has been proved experimentally and has been used in determining the energy of the exciting γ rays. A discussion of the subject of photoelectron emission by X rays has been given by A. H. Compton.

When γ rays pass through thin layers the β radiation leaving the layer on the side where the X ray beam emerges is more intense than that on the side where the X ray beam is incident. The asymmetry of this β radiation was more marked for light atoms than for heavy atoms; also for hard than for soft γ rays.

Scattering of gamma rays.—When γ rays are incident on matter γ rays may be detected on all sides of the piece as if emitted by it. γ rays so re-radiated were called "secondary" γ rays. These secondary γ rays appear to be really a mixture of two types: (1) scattered primary γ rays; (2) fluorescent or characteristic X rays produced in the atoms of the secondary radiator by high velocity electrons liberated photoelectrically by the primary γ rays.

Ishino's values of the mass scattering coefficient for Al, Fe, and Pb are respectively, 0.045, 0.042, and 0.034 (cm^2/gm). The softening of the "secondary" γ rays is undoubtedly due to (1) the production of fluorescent radiation which may be in part (Compton) similar to the general "white" radiation emitted by an X-ray tube, and (2) a modification of the true primary scattered radiation. The scattering of γ rays by thin sheets indicates that the scattering per atom is nearly proportional to the atomic number, and that each electron appears therefore to act as an independent center for scattering whether it is one of a small number of electrons (Al) or one of a larger number (Pb). The scattered radiation on the emergent side is greater in amount than that on the incident side.

Comparison of gamma-ray sources.—The relative ionizing powers of different types of γ radiation need to be known if the quantity of any γ-ray emitter is to be determined by comparison with a radium standard. The amount of $MsTh_2$ in equilibrium with 1 g of Th, e.g., one month after separation of $MsTh_1$, gives a γ-ray ionization equivalent to that from 0.524×10^{-7} g Ra in equilibrium with its γ-ray products. The amount of ThC″ in equilibrium with 1 g Th gives a γ-ray ionization equivalent to that from 0.956×10^{-7} g Ra in equilibrium with its γ-ray products. Since $MsTh_1$ and Ra are isotopes, chemical separation is impossible, and since the γ rays compared are of nearly the same quality the detection and estimation of mesothorium impurities in radium by γ-ray measurements (usually used for standardization) is somewhat difficult. Hahn and Bothe have shown how to distinguish between these materials by absorption experiments. Mme. Curie has shown that the ratio of the total heating effect to the γ-ray activity is also characteristic of the proportion of mesothorium in a mixture of the two.

Table 649

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ABSORPTION OF CHARACTERISTIC GAMMA RAYS

Source and type of decay	Level assumed	In Aluminum: Half value thickness D cm	In Aluminum: Absorption coefficient μ cm^{-1}	In Aluminum: Mass absorption coefficient μ/ρ cm^2/gm	In Lead: Half value thickness D cm	In Lead: Absorption coefficient μ cm^{-1}	In Lead: Mass absorption coefficient μ/ρ cm^2/gm
UX_1 β	L	0.029	24	8.9			
	K	.99	.70	.26	0.30	2.3	0.20
UX_2 β	*	4.95	.140	.052	.96	.72	.064
Io α	M	.00064	1088	400			
	L	.0307	22.7	8.35			
	K	1.7	.41	.15			
Ra α	M	.0020	354	130			
	L	.043	16.3	6			
	*	2.6	.27	.1			
RaB β	M	.0030	230	85	.015	46	4.1
	L	.0173	40	15	.15	4.6	.41
	K	1.22	.57	.21	.46	1.5	.13
RaC + C″		.0030	230	85	.015	46	4.1
α, β		.0173	40	15	.15	4.6	.41
	*	3	.230	.085	.46	1.496	.132
	*	5.46	.127	.047	1.30	.535	.047
RaD β	L	.0154	45	16.7			
	K	.70	1.17	.37			
RaE β		.0154	45	16.7			
		.70	.99	.37			
	*	2.79	.25	.092			
RaF β	M	.00120	2700	215			
	L		46				
RdAC α	L	.28	25	9.3			
	*	3.65	.190	.070			
AcB β	M	.0058	120	44			
	L	.022	31	11.5			
	K	1.54	.45	.167			
AcC″ β	*	3.50	.198	.073			
$MsTh_2$ β	L	.027	26	9.6	.061	11.3	1.00
					.25	2.8	.25
	*	6.0	.116	.043	.99	.70	.062
RdTh					small	great	great
ThB β	M	.0043	160	59			
	L	.022	32	11.9			
	K	1.9	.36	.133			
ThC″ β	*	7.2	.096	.036	1.5	.46	.041

Potassium, β rays, μ_{Fe}, 0.19; μ_{Pb}, 0.14; μ_{Al}, 0.065,* 0.14*.

* Nucleus.

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TABLE 650.—Characteristic Gamma-Ray Wave Lengths and Energies Estimated from Absorption and Scattering

(Taken from Kovarik, McKeehan, Nat. Res. Council Bull., 51, 1929.)

Source		λ cm × 10^{-11}	Energy volts × 10^5	Energy ergs × 10^{-7}	Reference
UX_1	90 UI	903	0.137	0.217	Lang, '21
		220	.562	.894	"
UX_2	91 U	115	1.069	1.701	"
Io	90 Ra	4140	.030	.047	"
		880	.140	.223	"
		176	.699	1.112	"
Ra	88 Ra	2640	.047	.074	"
		771	.160	.260	"
		150	.822	1.308	"
RaB	82 RaI	2230	.055	.088	"
		1110	.111	.177	"
		202	.610	.970	"
RaC	83 RaI	141	.877	1.395	"
		111	1.112	1.769	"
		27.5	4.483	7.135	Compton, '21
		20	6.165	9.810	Owen-Fleming, Fage, '24
		17	7.252	11.54	Ahmad, '24
RaD	82 RaII	1160	.106	.169	Lang, '21
		1063	.116	.184	O, F, F, '24
		252	.489	.778	Lang, '21
		290	.425	.677	Meitner, '22
RaF	84 RaIII	3230	.038	.061	Lang, '21
RdAc	90 Ac	918	.134	.214	"
		130	.946	1.506	"
AcB	82 AcI	1720	.072	.114	"
		1000	.123	.192	"
		184	.670	1.066	"
AcC″	81 Ac	132	.931	1.481	"
$MsTh_2$	89 Th	932	.132	.210	"
		107	1.153	1.834	"
ThB	82 ThI	1930	.064	.102	"
		1010	.122	.194	"
		168	.733	1.166	"
ThC″	83 Th	99	1.243	1.978	"

TABLE 651.—Nuclear Energy Deduced from Gamma-Ray Spectra

(Kovarik, McKeehan, Nat. Res. Council Bull., 51, 1925.)

Nucleus	Energy of level volts × 10^5	No. of γ rays accounted for (each counted twice)	Nucleus	Energy of level volts × 10^5	No. of γ rays accounted for (each counted twice)
RaB	0	4	TnC″	0	7
	.537	6		.41	5
	.625 (0.628)	4		.56	2
	2.571 (2.572)	4		2.28	2
	2.942	3		2.48	4
	4.048	3		2.54	3
	5.31	4		2.74	3
RaC	0	2		5.11	5
	.59	4		9.02	3
	.70	1			
	3.07	2			
	3.30	2			
	4.45	1			

Ellis, Skinner, 1924; values in 3rd column of TnC″ supplied by Kovarik, McKeehan.

TABLE 652

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GAMMA-RAY WAVE LENGTHS AND ENERGIES MEASURED BY CRYSTAL REFLECTION

(Taken from Kovarik, McKeehan, Nat. Res. Council Bull., 51, 1929.)

PART 1

Reflection from (100) Planes of Rock Salt (d = 2.814 × 10⁻⁸cm)

Source		θ	λ cm × 10⁻¹¹	Energy volts × 10⁵	Energy ergs × 10⁻⁷	Int.	Ref.
RaB	82 RaI	14°—02′	1365	0.0903	0.1437	m.	1
		13°—52′	1349	.0914	.1455	m.	1
		13°—31′	1315	.0937	.1492	w.	1
		13°—14′	1288	.0957	.1523	w.	1
		13°—00′	1266	.0974	.1550	w.	1
		12°—31′	1220	.1011	.1609	w.	1
		12°—16′	1196	.1031	.1641	m.	1
		12°—03′	1175	.1049	.1670	s.	1
		11°—42′	1141	.1080	.1719	m.	1
		11°—17′	1101	.1120	.1782	w.	1
		11°—00′	1074	.1148	.1827	w.	1
		10°—48′	1055	.1169	.1860	w.	1
		10°—32′	1029	.1198	.1907	m.	1
		10°—18′	1006	.1225	.1950	m.	1
		10°—03′	982	.1255	.1998	s.	1
		9°—45′	953	.1294	.206	m.	1
		9°—23′	918	.1344	.214	w.	1
		8°—43′	853	.1446	.230	m.	1
		8°—34′	838	.1471	.234	m.	1
		8°—16′	809	.1524	.242	m.	1
		8°—06′	793	.1555	.247	m.	1
		4°—22′	428	.288	.458		2, 3
		4°—00′	393	.314	.500		2, 3
		3°—18′	324	.381	.606		2, 3
		3°—00′	294	.419	.666		2, 3
		2°—40′	262	.471	.749		2, 3
		2°—28′	242	.509	.810		2, 3
		2°—20′	229	.538	.856		2, 3
		2°—00′	196.4	.628	.999		2, 3
		{1°—43′	168.6	.731	1.164		2, 3
		{1°—37′	158.8	.776	1.236		2, 3
		1°—24′	137.5	.897	1.427		2, 3
RaC	83 RaI	1°—10′	114.6	1.076	1.712		2, 3
		1°—00′	98.2	1.255	1.998		2, 3
		0°—43′	70.4	1.752	2.79		2, 3

PART 2

Reflection from (111) Planes of Calcite (d = 3.028 × 10⁻⁸ cm)

Source		θ	λ cm × 10⁻¹¹	Energy volts × 10⁵	Energy ergs × 10⁻⁷	Ref.
RaC	83 RaI	0°—41′	72.2	1.707	2.716	4 Note
		0°—37.5′	66.1	1.866	2.772	4
		0°—33′	58.1	2.121	3.375	4 Note
		0°—27.5′	48.4	2.545	4.050	4
		0°—21′	37	3.333	5.304	4
		0°—16′	28.1	4.374	6.961	4

NOTE.—Possibly second order.

References: 1 Rutherford-Andrade (s. strong, m. medium, w. weak), '14.
2 Rutherford-Andrade, '14.
3 Rutherford, '14.
4 Kovarik, '22.

TABLE 653

RADIOACTIVITY

QUANTITIES IN RADIOACTIVE EQUILIBRIUM

(Taken from 1930 Report International Radium Standards Commission, Rev. Mod. Phys., 3, 427, 1931.)

		T	M (mass units) for Ra = 1	for UI = 1
	UI	$1.39\cdot10^{17}$s	$2.94\cdot10^{6}$	1.00
	UX_1	$2.12\cdot10^{6}$	$4.4\cdot10^{-5}$	$1.5\cdot10^{-11}$
		$(2.06)10^{6}$	$(4.3)\cdot10^{-5}$	
99.65%	UX_2	68.4	$1.4\cdot10^{-9}$	$5\cdot10^{-16}$
.35%	UZ	$2.4\cdot10^{4}$	$1.7\cdot10^{-8}$	$6\cdot10^{-16}$
	UII	$9.4\cdot10^{12}$	$2.0\cdot10^{2}$	$6.7\cdot10^{-5}$
3%	UY	$8.88\cdot10^{4}$	$5.6\cdot10^{-8}$	$1.9\cdot10^{-14}$
97%	Io	$2.6\cdot10^{12}$s	52.7	
	Ra	$5.02\cdot10^{10}$	1.00	
	Rn	$3.303\cdot10^{5}$	$6.47\cdot10^{-6}$	
	RaA	183	$3.52\cdot10^{-9}$	
	RaB	$1.61\cdot10^{3}$	$3.04\cdot10^{-8}$	
	RaC	$1.18\cdot10$	$2.23\cdot10^{-8}$	
99.96%	RaC′	ca 10^{-6}	ca $2\cdot10^{-19}$	
.04%	RaC″	79.2	$6\cdot10^{-13}$	
	RaD	$6.94\cdot10^{8}$	$1.28\cdot10^{-2}$	
	RaE	$4.26\cdot10^{5}$ (4.9d)	$7.9\cdot10^{-6}$	
		$4.32\cdot10^{5}$ (5.0d)	$8.0\cdot10^{-6}$	
Po =	RaF	$1.21\cdot10^{7}$	$2.24\cdot10^{-4}$	
			for Ra = 1 and 3% branching fraction	
	Pa	$1.01\cdot10^{12}$s	.62	
	Ac	$4.23\cdot10^{8}$	$2.5\cdot10^{-4}$	
		$(6.3\cdot10^{8} = 20$ yr)	$(3.7\cdot10^{-4})$	
	RdAc	$1.63\cdot10^{6}$	$9.8\cdot10^{-7}$	
	AcX	$9.7\cdot10^{5}$	$5.8\cdot10^{-7}$	
	An	3.92	$2.27\cdot10^{-12}$	
	AcA	$2\cdot10^{-3}$	$1.14\cdot10^{-15}$	
	AcB	$2.16\cdot10^{-3}$	$1.21\cdot10^{-9}$	
	AcC	130	$7.2\cdot10^{-11}$	
.32%	AcC′	ca 10^{-3}	ca $2\cdot10^{-18}$	
99.68%	AcC″	286	$1.57\cdot10^{-10}$	
		(283)	$1.55\cdot10^{-10}$	
			for Th = 1	for $MsTh_1$ = 1
	Th	$5.6\cdot10^{17}$s	1.00	$2.7\cdot10^{9}$
	$MsTh_1$	$2.1\cdot10^{8}$	$3.68\cdot10^{-10}$	1.00
	$MsTh_2$	$2.21\cdot10^{4}$	$3.88\cdot10^{-14}$	$1.05\cdot10^{-4}$
	RdTh	$6.0\cdot10^{7}$	$1.05\cdot10^{-10}$	.286
	ThX	$3.14\cdot10^{5}$	$5.41\cdot10^{-13}$	$1.47\cdot10^{-3}$
	Tn	54.5	$9.23\cdot10^{-17}$	$2.50\cdot10^{-7}$
	ThA	.14	$2.32\cdot10^{-19}$	$6.31\cdot10^{-10}$
	ThB	$3.82\cdot10^{4}$	$6.23\cdot10^{-14}$	$1.69\cdot10^{-4}$
	ThC	$3.63\cdot10^{3}$	$5.92\cdot10^{-15}$	$1.61\cdot10^{-5}$
65%	ThC′	ca 10^{-9}	ca 10^{-27}	ca $3\cdot10^{-18}$
		or 10^{-6}	10^{-14}	$3\cdot10^{-15}$
35%	ThC″	186	$1.04\cdot10^{-16}$	$2.83\cdot10^{-7}$

TABLE 654
CATHODE RAYS

Prepared by W. W. Nicholas, Bur. Standards

Cathode rays are swiftly moving electrons, and thus are of the same nature as β rays (see tables on radioactivity, pages 526 to 528). They are produced in gas discharge tubes. At comparatively low pressures the cathode rays thus produced have a nearly uniform velocity. Free electrons are emitted from hot bodies (Table 667), especially if the heated substance is coated with barium, calcium, or strontium oxide (Wehnelt cathode). These electrons can be given any desired speed if the heated substance (usually in the form of a wire) be enclosed in an evacuated tube and the difference of potential (V) applied between the wire (cathode) and another electrode (anode, anticathode, or target). The speed (v) of the cathode rays, expressed as a fractional part (β) of the speed of light ($\beta = v/c$, where c is the speed of light), when they have fallen through the entire potential difference, is given by the formula (corrected for the relativity change of mass)

$$V = 508.1 \{ (1 - \beta^2)^{\frac{1}{2}} - 1 \}$$

where V is in absolute kilovolts. The equivalent power series,

$$V = 254.0 \{ \beta^2 + (\tfrac{3}{4})\beta^4 + (\tfrac{5}{8})\beta^6 + (\tfrac{35}{64})\beta^8 \ldots . \},$$

is useful for calculations at low and intermediate speeds (error is about 1% for $\beta = 0.60$, using terms given here). A tabulation of the corresponding values of V (absolute kilovolts) and β follows. An electron speed of 0.2 cm/sec. is spoken of, e.g., as a 10.5 kilovolt electron, or as having an equivalent voltage of 10.5 kv.

β	V	β	V	β	V	β	V	β	V
0.02	0.1017	0.22	12.76	0.42	51.77	0.62	139.5	0.82	379.6
.04	.4070	.24	15.30	.44	57.71	.64	153.2	.84	428.3
.06	.9170	.26	18.10	.46	64.13	.66	168.2	.86	487.6
.08	1.634	.28	21.17	.48	71.08	.68	184.9	.88	561.6
.10	2.560	.30	24.53	.50	78.60	.70	203.4	.90	657.5
.12	3.699	.32	28.20	.52	86.75	.72	224.1	.92	788.3
.14	5.054	.34	32.19	.54	95.58	.74	247.3	.94	981.1
.16	6.631	.36	36.51	.56	105.2	.76	273.7	.96	1307
.18	8.436	.38	41.20	.58	115.6	.78	303.8	.98	2045
.20	10.48	.40	46.28	.60	127.0	.80	338.7		

Cathode rays whose direction of motion is perpendicular to the direction of a uniform magnetic field (H) describe a circular path of radius (r) according to the formula (corrected for relativity change of mass of electron)

$$Hr = 1695 \{ \beta(1 - \beta^2)^{\frac{1}{2}} \}$$

where H is expressed in gauss and r in cm.

When they impinge on matter, cathode rays are deflected from their original direction of motion. These deflections grade all the way from 180° "reflections" to the "diffusion" corresponding to deflections through very small angles. The large-angle deflections are ordinarily comparatively infrequent. However, when the substance struck by the cathode rays is crystalline, certain directions may be preferred by the deflections. Here the beam of cathode rays behaves as though it consisted of a train of waves of wave length $\lambda_e = 0.02428/\beta$, where λ_e is in Angstroms. The preferred directions for the "reflected" cathode ray beams may be calculated from the Bragg formula (see Siegbahn's "X-ray Spectroscopy"). The simple Bragg formula is quite limited in application here, however, since refraction in the crystal is very appreciable for the cathode ray beams. In general, the cathode rays which have been deflected by matter will have lost speed, but the rays which have undergone these "preferred" deflections remain of the same speed as the primary cathode beam.

Cathode rays lose speed on penetrating matter. The losses of speed by individual cathode particles grade from complete stoppage to no loss of speed. The majority of the cathode particles, however, lose speed according to the relation (Thomas-Whiddington-Bohr law)

$$\beta_0^4 - \beta^4 = ax$$

where β_0 is the initial speed, and β the speed after traversing a path length x in the material (x to be measured in cm along the actual curved path), and a is a constant roughly equal to 6.5ρ where ρ is the density of the material in g/cm³. A convenient form for the expression is the following. Note that the two forms are not equivalent except at very low speeds (experiment has not yet decided between the two):

$$V_0^2 - V^2 = bx$$

where V_0 and V are the initial and final "equivalent voltages" (see above) of the cathode rays, in kv, and b is a constant roughly equal to $40 \times 10^4\rho$. A tabulation of experimental values of a and b for various materials follows:

RÖNTGEN RAYS (X RAYS)

TABLE 655.—Constants for Cathode-Ray Speeds in Matter

Material	a	b
Beryllium	12.	0.75×10^6
Aluminum	17.	1.1 "
Copper	56.	3.6 "
Silver	66.	4.2 "
Gold	138.	9.0 "
Moist air, 76 cm, 18° C	0.0062	0.44×10^3

TABLE 656.—X-Ray Emission

X Rays are generated whenever and wherever swiftly moving electrons (cathode rays) strike matter. This process occurs in gas discharge tubes at moderately low pressures (about 0.001 to 0.01 mm Hg); the gas-filled X-ray tube is based on this principle. The Coolidge tube, in which the gas pressure is so low (less than 10^{-4} mm Hg) as not to play a part, is superior for most purposes: the electrons, supplied by a hot filament incorporated in the cathode, are given a high velocity by the application of a high potential (as high as 300,000 v, in certain types); these cathode rays are directed against an area ("focal spot") on the anode ("target," "anticathode") where the X rays are generated.

These X rays are of two types: continuous spectrum rays ("heterogeneous," "general," or "white" radiation) and characteristic rays (line spectra).

Continuous spectrum X rays are a direct result of the acceleration of the cathode rays due to their close contacts with the atoms of the anticathode. The spectrum energy distribution of this radiation, from a tube whose electrodes are maintained at a constant potential difference (V), is described very roughly by the formula (for a more accurate type of formula, see the I.C.T. vol. 6)

$$J_\nu d\nu = C(\nu_0 - \nu)e^{-c/\nu^3}d\nu \qquad \nu \leq \nu_0 \qquad (1)$$

for an energy-frequency graph, or by

$$J_\lambda d\lambda = (K/\lambda^2)\{1/\lambda_0 - 1/\lambda\}e^{-k\lambda^3}d\lambda \qquad \lambda \geq \lambda_0 \qquad (2)$$

for an energy-wave length graph. In these two formulae, J_ν or J_λ is the energy between frequencies, ν and $\nu + d\nu$, or wave lengths λ and $\lambda + d\lambda$, respectively, e, the base of natural logarithms, and ν_0 and λ_0 the highest frequency and shortest wave length, respectively of the spectrum ("high frequency limit," "short wave-length limit," "spectrum limit"). For X rays generated inside the anticathode c and k are zero; this simplifies the formulae, the exponential term becoming unity. For the X ray obtained outside the tube, c and k have values, estimates of which are tabulated in Table 660. The factor, c or k, determines the energy of the X rays; the convenient way to evaluate this energy is, instead of assigning numerical values to c or k, to evaluate E_1 and I_1 (Table 660). ν_0 and λ_0 depend only on the voltage (V), the relations being:

$$\lambda_0 = 12.336/V \qquad (3)$$

$$\nu_0 = 243.0 \times 10^{15} V \qquad (4)$$

(λ and λ_0 are expressed throughout this section in Angstrom units, 10^{-8} cm, and v and v_0 are in sec.$^{-1}$, and V is in kilovolts absolute.)

The energy of the continuous spectrum X rays, E_1, produced in the anticathode ordinarily comprises a major fraction of the total X-ray energy generated; the energy of the characteristic rays, E_2, comprises the minor fraction. ($E_1 + E_2$) is only an exceedingly small fraction of the electrical energy, E_3, supplied to the tube. E_1/E_3 is called the efficiency of production of continuous spectrum X rays, and is closely represented by the formula

$$E_1/E_3 = ZV \times 13 \times 10^{-7}.$$

where Z is the atomic number of the material of the anticathode, and V is expressed in kilovolts. On account of losses by absorption in the anticathode and in the walls of the tube only a small part of this energy generated inside the anticathode gets outside the tube. Table 660 supplies some numerical values of this "usable" energy, for tubes similar to the standard commercial types.

Characteristic X rays result from the ionization of atoms, either (1) by direct cathode ray impact, or (2) by absorption of X rays. In the anticathode of an X-ray tube both these processes occur. With a silver anticathode, for example, at any voltage between 35 and 80 kv, process (1) accounts for about 65% of the energy of the characteristic rays.

Table 657

RÖNTGEN RAYS (X RAYS)

EMISSION LINES AND CRITICAL ABSORPTION LIMITS

(in Angstroms)

The characteristic rays group themselves naturally into several groups, K, L, M, etc.; for any given element the lines in one group differ from each other in wave length by amounts which are small compared with the differences between separate groups. The wave lengths of the characteristic rays vary only with the material of the anticathode; these wave lengths, for some of the more prominent lines are given in the table below.

λ_a is the wave length of the critical absorption limit associated with the emission lines listed in the same subgroup. Taken by permission from Compton, "X-rays and Electrons."

Atomic number, Element	K					L	Group
	K					L_1	Sub-group
	λ_a	γ_1	β_1	α_1	α_2	λ_a	
1 H	911.76	....	....	....	....	....	1 H
2 He	524	....	....	....	....	....	2 He
3 Li	235	....	....	....	....	2500	3 Li
4 Be	133	....	....	....	....	1360	4 Be
5 B	84	....	....	....	....	580	5 B
6 C	49.3	....	....	....	....	380	6 C
7 N	36.5	....	....	....	....	300	7 N
8 O	24.6	....	....	....	....	250	8 O
9 F	18.6	....	....	....	....	210	9 F
10 Ne	14.5	....	absent	18.37		180	10 Ne
11 Na	....	....	11.591	11.8836		146	11 Na
12 Mg	*9.5112* *	....	9.5345	9.86775		117	12 Mg
13 Al	*7.9470*	....	7.9405	8.31940		101	13 Al
14 Si	....	....	6.7393	7.10917		84	14 Si
15 P	*5.7580*	....	5.7890	6.14171		69	15 P
16 S	*5.0123*	....	5.0213	5.36090	5.36375	56	16 S
17 Cl	*4.3844*	....	4.3946	4.71821	4.72136	46	17 Cl
18 A	*3.8657*	....	....	....	....	37	18 A
19 K	*3.4345*	....	3.44680	3.73368	3.73706	33.1	19 K
20 Ca	*3.0633*	....	3.08343	3.35169	3.35495	28.9	20 Ca
21 Sc	*2.7517*	....	2.77394	3.02503	3.02840	25.4	21 Sc
22 Ti	*2.4937*	2.4937	2.50898	2.74317	2.74681	22.5	22 Ti
23 Va	*2.2653*	2.2646	2.27972	2.49835	2.50213	20.0	23 Va
24 Cr	*2.0648*	2.0670	2.08045	2.28484	2.28895	17.7	24 Cr
25 Mn	*1.8893*	1.8932	1.90591	2.09732	....	16.0	25 Mn
26 Fe	*1.7377*	1.7406	1.75272	1.93230	1.93651	14.6	26 Fe

* The values in italics are observed values. Other critical absorption limits are computed or interpolated.

RÖNTGEN RAYS (X RAYS)
EMISSION LINES AND CRITICAL ABSORPTION LIMITS
(in Angstroms)

Atomic number, Element	K					L	Group
	K					L_1	Sub-group
	λ_a	γ_1	β_1	α_1	α_2	λ_a	
24 Cr	*2.0648*	2.0670	2.08045	2.28484	2.28895	17.7	24 Cr
25 Mn	*1.8893*	1.8932	1.90591	2.09732	....	16.0	25 Mn
26 Fe	*1.7377*	1.7406	1.75272	1.93230	1.93651	14.6	26 Fe
27 Co	*1.6018*	1.6054	1.61713	1.78528	1.78956	13.2	27 Co
28 Ni	*1.4890*	1.4854	1.49703	1.65461	1.65854	12.1	28 Ni
29 Cu	*1.3785*	1.3780	1.38933	1.53730	1.54116	11.0	29 Cu
30 Zn	*1.2963*	1.28097	1.29260	1.43206	1.43587	....	30 Zn
31 Ga	*1.1902*	....	1.20591	1.33785	1.34161	....	31 Ga
32 Ge	*1.1146*	1.11463	1.12671	1.25130	1.25521	....	32 Ge
33 As	*1.0435*	1.04290	1.05518	1.17344	1.17741	....	33 As
34 Se	*.9790*	.99792	.99027	1.10241	1.10642	....	34 Se
35 Br	*.9179*	.91827	.93085	1.03756	1.04160	....	35 Br
37 Rb	*.8143*	.81484	.82703	.92360	.92772	....	37 Rb
38 Sr	*.7693*	.76917	.78151	.87360	.87754	....	38 Sr
39 Y	*.7255*	.72663	.73932	.82700	.83118	....	39 Y
40 Zr	*.6872*	.68835	.70048	.78429	.78850	....	40 Zr
41 Nb	*.6503*	.65255	.66449	.74457	.74882	....	41 Nb
42 Mo	*.6184*	.61969	.63124	.70780	.71208	4.303	42 Mo
44 Ru	*.5584*	.56048	.57143	.64181	.64615	....	44 Ru
45 Rh	*.5330*	.53313	.54470	.61201	.61637	3.598	45 Rh
46 Pd	*.5057*	.50963	.51972	.58419	.58858	....	46 Pd
47 Ag	*.4850*	.48607	.49630	.55821	.56264	*3.2605*	47 Ag
48 Cd	*.4632*	.46438	.47428	.53386	.53829	....	48 Cd
49 In	*.4434*	.44409	.45373	.51103	.51546	....	49 In
50 Sn	*.4242*	.42485	.43439	.48948	.49396	....	50 Sn
51 Sb	*.4065*	.40711	.41624	.46933	.47386	*2.6327*	51 Sb
52 Te	*.3896*	.39035	.39924	.45037	.45491	*2.5026*	52 Te
53 I	*.3737*	.37483	.38341	.43249	.43703	*2.3819*	53 I
55 Cs	*.3444*	....	.352	.398	.402	*2.1605*	55 Cs
56 Ba	*.3307*	....	.343	.388	.393	*2.0602*	56 Ba
57 La	*.3186*	....	.329	.372	.376	*1.971*	57 La
58 Ce	*.3065*	....	.314	.355	.360	*1.887*	58 Ce
59 Pr	*.2949*	....	.301	.342	.347	*1.808*	59 Pr
60 Nd	*.2840*	....	.292	.330	.335	*1.736*	60 Nd
62 Sm	*.2640*	....	....	....	....	1.598	62 Sm
63 Eu	*.2545*	....	....	....	....	1.537	63 Eu
64 Gd	*.2459*	....	....	....	....	1.477	64 Gd
65 Tb	*.2376*	....	....	....	....	1.419	65 Tb
66 Dy	*.2301*	....	....	....	....	1.367	66 Dy
67 Ho	*.2216*	....	....	....	....	1.316	67 Ho
68 Er	....	....	....	....	....	1.270	68 Er
69 Tu	*.2085*	....	....	....	....	1.220	69 Tu
70 Yb	*.2016*	....	....	....	....	1.177	70 Yb
71 Cp	*.1951*	....	....	....	....	1.137	71 Cp
72 Hf	*.1901*	....	....	....	....	1.098	72 Hf
73 Ta	*.1836*	.18452	.18991	.21488	.21973	1.060	73 Ta
74 W	*.1781*	.17898	.18422	.20862	.21345	*1.024*	74 W
76 Os	*.168*	.16875	.17361	.19645	.20131	....	76 Os
77 Ir	....	.16376	.16850	.19065	.19550	....	77 Ir
78 Pt	*.1578*	.15887	.16370	.18523	.19004	*.8921*	78 Pt
79 Au	*.1524*	.15426	.15902	.17996	.18483	*.8613*	79 Au
80 Hg	*.1479*	....	....	....	....	*.8335*	80 Hg
81 Tl	*.1427*	.14539	.15011	.16980	.17466	*.8055*	81 Tl
82 Pb	*.1385*	.14125	.14606	.16516	.17004	*.7803*	82 Pb
83 Bi	*.1346*	....	.14205	.16041	.16525	*.7565*	83 Bi
90 Th	*.1127*	....	....	....	....	*.6044*	90 Th
92 U	*.1075*	.10842	.11187	.12640	.13095	*.5685*	92 U

RÖNTGEN RAYS (X RAYS)

EMISSION LINES AND CRITICAL ABSORPTION LIMITS (IN ANGSTROMS)

Atomic number, Element	L (continued)							Group
	L_{II}			L_{III}				Sub-group
	λ_a	γ_1	β_1	λ_a	α_1	α_2	β_2	
24 Cr	21.2	....	21.35	21.6	....	21.69	....	24 Cr
25 Mn	18.7	....	19.17	19.0	....	19.48	....	25 Mn
26 Fe	17.1	....	17.27	17.5	....	17.60	....	26 Fe
27 Co	15.3	....	....	15.2	....	....	....	27 Co
28 Ni	14.6	....	....	14.9	....	....	....	28 Ni
29 Cu	12.8	....	....	13.1	....	13.309	....	29 Cu
30 Zn	....	....	11.951	....	....	12.222	....	30 Zn
31 Ga	....	....	....	....	....	....	....	31 Ga
32 Ge	....	....	....	....	....	10.413	....	32 Ge
33 As	....	....	9.3940	....	....	9.6503	....	33 As
34 Se	....	....	8.7172	....	....	8.9706	....	34 Se
35 Br	....	....	8.1076	....	....	8.3566	....	35 Br
37 Rb	....	....	7.0604	....	....	7.3027	....	37 Rb
38 Sr	....	....	....	....	....	6.8478	....	38 Sr
39 Y	....	....	....	....	....	6.4349	....	39 Y
40 Zr	5.386	5.3730	5.8228	5.577	....	6.0559	5.5734	40 Zr
41 Nb	5.027	5.0241	5.4796	5.228	5.7113	5.717	5.2253	41 Nb
42 Mo	4.702	4.7111	5.1658	4.897	5.3943	5.400	4.9092	42 Mo
44 Ru	....	4.17282	4.61100	....	4.83567	4.84367	4.3619	44 Ru
45 Rh	3.940	3.9357	4.1221	4.128	4.58778	4.59556	4.1221	45 Rh
46 Pd	....	3.71636	4.13730	....	4.35850	4.36660	3.9007	46 Pd
47 Ag	*3.2605*	3.51485	3.92664	*3.6844*	4.14564	4.15382	3.69383	47 Ag
48 Cd	....	3.32800	3.73008	....	3.94782	3.95636	3.5064	48 Cd
49 In	....	3.15529	3.54783	....	3.76367	3.77242	3.3312	49 In
50 Sn	....	2.99493	3.37792	....	3.59218	3.60108	3.1679	50 Sn
51 Sb	*2.8310*	2.84507	3.21836	*2.9945*	3.43177	3.44075	3.0166	51 Sb
52 Te	*2.6837*	2.70647	3.06997	*2.8470*	3.28199	3.29100	2.8761	52 Te
53 I	*2.5483*	2.57748	2.93093	*2.7124*	3.14166	3.15087	2.74608	53 I
55 Cs	*2.3073*	2.34252	2.67784	*2.4678*	2.88610	2.89560	2.5064	55 Cs
56 Ba	*2.1995*	2.23660	2.56224	*2.3577*	2.76964	2.77904	2.3993	56 Ba
57 La	*2.098*	2.13720	2.45330	*2.250*	2.65968	2.66893	2.2980	57 La
58 Ce	*2.007*	2.04433	2.35100	*2.158*	2.55600	2.56511	2.2041	58 Ce
59 Pr	*1.920*	1.95681	2.25390	*2.072*	2.45770	2.46763	2.1148	59 Pr
60 Nd	*1.842*	1.87383	2.16221	*1.902*	2.36531	2.37563	2.0314	60 Nd
62 Sm	1.692	1.72309	1.99357	*1.841*	2.19501	2.20568	1.8781	62 Sm
63 Eu	1.624	1.6543	1.91631	*1.773*	2.11633	2.12733	1.8082	63 Eu
64 Gd	1.560	1.55863	1.84246	*1.709*	2.04193	2.05262	1.7419	64 Ga
65 Tb	1.499	1.5266	1.77268	*1.646*	1.97149	1.98231	1.6790	65 Tb
66 Dy	1.442	1.4697	1.70658	*1.588*	1.90460	1.91564	1.6198	66 Dy
67 Ho	1.387	1.4142	1.64350	*1.532*	1.84098	1.85206	1.5637	67 Ho
68 Er	1.335	1.3623	1.58344	*1.480*	1.78040	1.79140	1.5106	68 Er
69 Tm	1.287	1.3127	1.5268	1.431	1.7228	1.7339	1.4602	69 Tm
70 Yb	1.240	1.2648	1.4725	1.383	1.66779	1.6789	1.4128	70 Yb
71 Cp	1.195	1.2203	1.4207	1.339	1.61551	1.62636	1.3672	71 Cp
72 Hf	1.152	1.1765	1.3711	1.294	1.56607	1.57704	1.3235	72 Hf
73 Ta	1.111	1.13471	1.32354	1.251	1.51825	1.5294	1.2810	73 Ta
74 W	*1.0726*	1.09553	1.27917	*1.2136*	1.47348	1.48452	1.24191	74 W
76 Os	....	1.02247	1.19459	....	1.38816	1.3982	1.16838	76 Os
77 Ir	....	.98841	1.15495	....	1.34834	1.35939	1.13287	77 Ir
78 Pt	*.9321*	.95545	1.11722	*1.0704*	1.31008	1.32121	1.09950	78 Pt
79 Au	*.9011*	.92437	1.08093	*1.0393*	1.27355	1.28489	1.06775	79 Au
80 Hg	*.8700*	.8935	1.0458	*1.0067*	1.2385	1.2497	....	80 Hg
81 Tl	*.8415*	.86529	1.01266	*9776*	1.20471	1.21603	1.00786	81 Tl
82 Pb	*.8133*	.83708	.97990	*.9497*	1.17202	1.18352	.97990	82 Pb
83 Bi	*.7874*	.81065	.94930	*.9216*	1.14115	1.1533	.95293	83 Bi
90 Th	*.6286*	.65103	.76259	*.7596*	.95342	.96524	.79108	90 Th
92 U	*.5918*	.61283	.71807	*.7214*	.90833	.92014	.75268	92 U

RÖNTGEN RAYS (X RAYS)

TABLE 657 (*Concluded*).—Emission Lines and Critical Absorption Limits (in Angstroms)

λ_a is the wave length of the critical absorption limit associated with the emission lines listed in the same subgroup. The italicized values are observed; other critical absorption limits are computed or interpolated.

Atomic number, Element	M									Group
	M_I	M_{II}	M_{III}		M_{IV}		M_V			Sub-group
	λ_a	λ_a	λ_a	γ	λ_a	β	λ_a	α_1	α_2	
13 Al	1100	2300	...	...	...	...	...	...	...	13 Al
25 Mn	79	190	...	...	...	...	...	...	...	25 Mn
42 Mo	24.2	29.9	30.7	...	52.4	...	53.0	...	...	42 Mo
52 Te	12.2	14.16	15.07	...	21.11	...	21.45	...	...	52 Te
66 Dy	6.042	6.699	7.731	...	9.28	9.323	9.54	...	...	66 Dy
67 Ho	5.797	6.403	7.068	...	8.85	8.943	9.12	...	9.150	67 Ho
68 Er	5.567	6.190	6.897	...	8.50	8.573	8.75	...	8.783	68 Er
70 Yb	5.151	5.621	6.254	...	7.83	7.891	8.08	8.011	8.125	70 Yb
71 Lu	4.963	5.427	6.067	...	7.542	7.582	7.78	7.803	7.820	71 Lu
72 Hf	4.746	5.216	5.864	...	7.19	7.286	7.42	...	7.521	72 Hf
73 Ta	4.557	5.038	5.674	6.301	6.87	7.001	7.10	...	7.238	73 Ta
74 W	4.392	4.827	5.447	6.085	6.617	6.745	6.845	6.952	6.973	74 W
76 Os	...	...	...	5.672	...	6.256	...	6.459	6.481	76 Os
77 Ir	...	...	...	5.484	...	6.030	...	6.223	6.250	77 Ir
78 Pt	3.746	4.083	4.700	5.303	5.618	5.820	5.830	6.026	6.041	78 Pt
79 Au	3.605	3.895	4.518	5.131	5.386	5.619	5.594	5.812	5.831	79 Au
81 Tl	3.329	3.597	4.160	4.806	4.934	5.233	5.157	5.427	5.443	81 Tl
82 Pb	3.213	3.477	4.035	4.666	4.786	5.065	4.982	5.250	5.273	82 Pb
83 Bi	3.081	3.333	*3.894*	4.513	*4.569*	4.894	*4.762*	5.078	5.107	83 Bi
90 Th	*2.388*	*2.571*	*3.058*	3.657	*3.552*	3.931	*3.721*	4.097	4.129	90 Th
92 U	*2.228*	*2.385*	*2.873*	3.472	*3.326*	3.709	*3.491*	3.885	3.901	92 U

TABLE 658.—Probabilities of Ionization in K and L Shells

An atom ionized, in the K shell, say, by one of the two processes described, can either (a) radiate a quantum of K characteristic radiation, or it can (b) convert an equivalent amount of energy into an ionization (with photoelectric emission) of its own outer shells L, M, etc. (compound photoelectric effect). The probability (u) of occurrence of process (a) subsequent to the ionization of an atom depends on the atom, and on the particular shell ionized. Some numerical values for the probability u are given in the table below.

Values in parentheses are comparatively uncertain.

Ionization in the K shell

Element	A	Cr	Fe	Co	Ni	Cu	Zn	Se	Br	Kr	Sr	Mo	Ag	I	Xe
u	.07	.23	.28	(.39)	.36	.38	.41	.54	.56	(.51)	.62	.68	(.86)	(.75)	(.71)

Ionization in the L shell

Element	Kr	Xe
u	(.13)	(.25)

RÖNTGEN RAYS (X RAYS)

TABLE 659.—Energy and Efficiency of Production of Characteritsic X Rays

The energy, E_2, of the characteristic rays, as produced inside the anticathode for a given tube and a given type of characteristic ray, varies with the material of the anticathode and the voltage applied to the tube. The rays in a particular subgroup (see Table 657) do not appear at all until a certain critical voltage, V_0, is reached, then all the rays of the subgroup appear at once. V_0 is given by the formula: $V_0 = 12.336/\lambda_a$, where V_0 is in absolute kilovolts and λ_a in Angstroms. In Table 657 values of λ_a associated with the various subgroups of emission lines are tabulated to the left of the particular lines with which they are associated.

The efficiency of production of the characteristic rays, which may be taken as E_2/E_3, is given roughly by the formula:

$$E_2/E_3 = G[(V - V_0)^2/V] \qquad V > V_0$$

where G is a constant whose dependence on the anticathode material and type of characteristic ray has not yet been broadly investigated. For a silver anticathode and a tube voltage of 50 kv, E_2/E_3 for the K rays is about 0.48×10^{-3}. Due to losses by absorption in the anticathode and walls of the tube only a part of the energy generated in the anticathode reaches the outside of the tube. The following table supplies some estimates of this "usable" energy for tubes similar to the standard commercial types. I_2, which is a measure of the useful characteristic ray energy, varies with voltage in a different manner than E_2, on account of the variation with voltage of the absorption in the anticathode. For $V_0 < V < 2V_0$, I_2 is roughly proportional to $(V - V_0)^n$, where n is usually between 3/2 and 2; but at higher voltages some measurements indicate that I_2 increases more slowly with voltage, approaching a limiting value in the neighborhood of $V = 6V_0$.

The relative intensities of the lines in a particular subgroup are independent of voltage for a given element; the variation from element to element is often negligible over long ranges of atomic number. In the K series, and at least for atomic numbers greater than 30, about 5/6 of the energy is contained in the two α lines; of these two, α_1 is the more intense in the ratio 2:1. In the L series of tungsten, at 22.75 kv, the ratio of the intensities α_1:α_2 is 10:1; β_1:β_2:β_3:β_4 have relative intensities 100:55:15:1; and γ_1:γ_2:γ_3:γ_4 have 100:14:18:6.

TABLE 660.—Energy and Quality of Emission X Rays

Type of tube (anticathode)	V kv	i ma	E_1 ergs/sec.	c sec.$^{-3}$	k A^3	$(E_2)_K$ ergs/sec.	I_1 at one m erg/sec. cm^2	I_2 at one m erg/sec. cm^2
Tungsten	40	1.0	1.23×10^6	0.15×10^{57}	5.5	....	2.2	0
"	69	"	3.66 "	.17 "	6.3	....	10	0
"	100	"	7.20 "	.20 "	7.4	....	22.5	7.3
"	150	"	17.3 "	.25 "	9.2	....	50	24.2
Silver	50	....	....	....	....	$.24 \times 10^6$	....	....

NOTE: V is the constant direct current potential difference maintained across the terminals of the tube. For varying voltages (as with a tube supplied directly from a transformer, or with a mechanical rectifier), where V is the peak voltage and i is the average current as read by a milliameter, all the values tabulated are decreased by an extent dependent on the voltage and current wave forms for the particular outfit used, and therefore difficult to specify here. i is the milliamperage tube current for tubes of the Coolidge type, but not for gas-filled tubes, where there are complicating factors. E_1 is the energy converted per sec., inside the anticathode, into continuous spectrum X rays. $(E_2)_K$ is a similar quantity for the K characteristic rays.

TABLE 660 (*continued*).—Energy and Quality of Emission X Rays

I_1 is the intensity in the continuous X rays obtained outside the tube at a distance of 1 meter from the focal spot, supposing no filtration other than the unavoidable filtration due to the walls of the tube (assumed equivalent to 1.23 mm of Al), anticathode, etc. For practical purposes, until more thorough data is at hand, I_1 may be assumed proportional to the atomic number of the material of the anticathode. It is expressed in ergs per sec. falling on a 1 cm^2 surface perpendicular to the X-ray beam. The orientation of the tube is supposed to be the usual one, with X rays taken off perpendicular to the cathode stream, and target face inclined at 45°. I_2 is a similar quantity for the K characteristic rays.

c and k are quantities contained in p. 537, which describe the spectrum distribution of the intensity I_1.

E_1 and E_2 are probably within 5% and 10%, respectively, of their correct values. I_1 and I_2 depend on the tube walls, the roughness of the target surface, etc., and on such accounts an estimate of accuracy is difficult to make; for a smooth target surface, inclined at 45°, and tube walls of 0.7 mm soda glass, the above values of I_1 and I_2 are probably correct to within 20%.

TABLE 661.—X-Ray Spectroscopy

When an X-ray beam is incident on a crystal in such a manner as to make a glancing angle θ with certain sets of parallel planes within the crystal (adjacent planes, containing large numbers of atoms, for best efficiency), these planes having an interplane spacing d, components of the beam of wave lengths λ, $\lambda/2$, $\lambda/3$, ... λ/n will be diffracted (or "reflected") according to the relation (Bragg law): $\lambda = 2d \sin\theta$. The angle between the directions of the original beam and the deviated beam is 2θ. Refraction in the crystal would introduce an additional factor in the above formula, but the effect is negligible for all ordinary work.

Values for d, the "lattice constant," for some of the commonly used crystals are tabulated below.

TABLE 662.—Lattice Constants of Crystals

Crystal	Surface	d in Angstroms at 18° C
Carborundum	(111)	2.49
Rock salt	Cleavage face	2.814
Calcite	Cleavage face	3.029
Quartz	Prism face	4.247
Gypsum	Cleavage face	7.577
K_4FeCN_6	(100)	8.408
Mica	Cleavage face	9.993
Sugar	(100)	10.57
Al_2O_3	(100)	11.23

For an extensive tabulation of X-ray data on crystals see the I. C. T., vol. 1.

TABLE 663.—Absorption and Scattering of X Rays; Fluorescenee

A beam of X rays loses energy as it traverses matter. For monochromatic rays, this loss of energy is given by the formula: $I/I_0 = e^{-\mu x}$ where I_0 and I represent respectively incident and emergent intensities of a parallel beam normal to a plate of absorbing material of thickness x, e is the base of natural logarithms, and μ is a constant depending only on the wave length of the x rays and the material of the plate.

For the most used range (wave lengths 0.1 to 1.4 Angstroms, and atomic numbers greater than 5; outside this range there are systematic deviations from the formulae) μ is approximated to about 5% or better by the formulae: (See next page.)

RÖNTGEN RAYS (X RAYS)

TABLE 663 (*continued*).—Absorption and Scattering of X Rays; Fluorescence

$$\mu/\rho = (1/A)(0.0136Z^4\lambda^3 + 0.32Z) \qquad \lambda < \lambda_k$$
$$\mu/\rho = (1/A)(0.0020Z^4\lambda^3 + 0.32Z) \qquad \lambda_k < \lambda < \lambda_{L_1}$$

ρ is the density, Z, the atomic no., A, the atomic weight of the material of the plate, λ, the wave length of the X rays, Angstrom units; x is in cm. Values for λ_k and λ_{L_1}, wave lengths at which materials have "critical absorption discontinuities," are listed in Table 657 under "X-ray Emission" as λ_a. Numerical values for μ/ρ, the "mass absorption coefficient," (A. H. Compton "X-rays and Electrons") are given in Table 665.

The first term in the brackets represents energy losses from "fluorescent," or "true," absorption; this first appears as energy of ionization of atoms and of photoelectrons. The ionized atoms then either emit characteristic X rays or use their energy for the photoelectric process; the quantitative relations between these are described in Table 660 under "X-ray Emission."

The second term is the energy lost by the X-ray beam by scattering. Except for the (usually small) amount of energy which goes into the production of "recoil electrons," it remains as X-ray energy which is simply redistributed as to direction of propagation, being radiated in all directions from the plate. The scattered radiation is of two parts, an "unmodified" (or "unshifted") part, and a "modified" (or "shifted") part. The former has the wave length of the original beam. The wave length of the modified part is longer ("Compton shift") than that of the original beam by an amount $\delta\lambda$ which varies with ϕ, the angle between the direction of the primary beam (of wave length λ), and the direction of that portion of the modified rays of wave length $\lambda + \delta\lambda$. The relation between $\delta\lambda$ and ϕ is $\delta\lambda$ (Angstrom units) $= 0.02428(1 - \cos\phi)$.

TABLE 664.—X-Ray Absorption and Chemical Combination

The wave lengths of the critical absorption limits of an element depend, to a very small extent, on the chemical combination of the "absorbing" element. The K absorption limit for phosphorus follows for various chemical combinations: R stands for any one of several metals.

Wave lengths, λ, in Angstroms

	λ	$\Delta\lambda$		λ	$\Delta\lambda$
$(RO)_3PO$	5.7507	.....	$(RN)_3PO$	5.7565	0.0058
$(RO)_2HPO$	5.7541	0.0034	$(RC)_3PS$	5.7632	.0125
$(RO)H_2PO$	5.7575	.0068	RO(RC)(H)PO	5.7581	.0074
$(RO)_2(RC)PO$	5.7551	.0044	$(RO)_3P$	5.7599	.0092
$(RO)(RC)_2PO$	5.7591	.0084	$(RC)_3P$	5.7676	.0169
$(RC)_3PO$	5.7604	.0097	$(RO)Cl_2P$	5.7602	.0095
$(RC)_4POR$	5.7630	.0123	$(RC)_3P,CuCl$	5.7645	.0138
$(RN)(Cl)_2PO$	5.7588	.0081	$(RO)_3P,CuCl$	5.7589	.0082
(RN)(RO)(Cl)PO	5.7559	.0052	P (violet)	5.7714	.0207
$(RN)(RO)_2PO$	5.7512	.0005	P (black)	5.7715	.0208
$(RN)_2(RO)PO$	5.7541	.0034	P (white)	5.7769	.0262

There result some conclusions probably of general application: ($\Delta\lambda$) in its value for some particular compound, depends only on what atoms are directly attached to the absorbing atom (e.g., the phosphorus limit $(RO)_3P$ does not depend on what metal is used for R). $\Delta\lambda$ depends on the *kind* of atom directly attached (compare $(RO)_3P$ with $(RC)_3P$) and on the *number* of these atoms (compare $(RO)_3P$ with $(RO)_3PO$). If any addition (any kind of atom) is made to a given set of atoms directly attached to the absorbing one, the limit is shifted toward a shorter λ (cf., $(RC)_3P$ with $(RC)_3PO$). Further, the wave length for the element when uncombined is usually greater than when attached chemically to other atoms (true for all of 11 elements investigated except sulphur). A variation of wave length is also usually shown for allotropic modifications of an element.

Table 665

MASS ABSORPTION COEFFICIENTS (μ/ρ)

Atomic number, Element	Wave lengths in Angstroms 0.017	0.057	0.080	0.100	0.125	0.150	0.175	0.200	0.250	0.300	0.350	0.400
1 H	0.117	...	...	...	0.3	0.4	0.4	0.4	0.39	0.42	0.44	0.45
3 Li	...	...	...	...	...	...	...	...	...	.172	.188	.208
6 C	.060	...	0.140	0.146	.152	.160	.162	.170	.184	.197	.216	.240
7 N	...	...	...	...	...	.163	.171	.177	.193	.224	.251	...
8 O	.059	...	...	...	.146	.163	.174	.183	.208	.240	.285	.338
12 Mg	.057	...	...	...	.162	.175	.202	.232	.311	.430	.612	.875
13 Al	.058	0.07	.143	.164	.178	.201	.231	.269	.370	.531	.756	1.05
16 S	.058	...	.152	.190	.204	.272	.333	.42	.63	.93	1.32	1.78
26 Fe	.058	.08	.232	.265	.399	.572	.79	1.07	1.93	3.18	4.94	7.17
27 Co	...	...	...	...	.42	.60	.84	1.17	2.12	3.52	...	...
28 Ni	.059	...	.261	.328	.475	.68	1.00	1.40	2.50	4.10	6.22	...
29 Cu	.057	...	.263	.323	.49	.77	1.10	1.53	2.75	4.47	6.91	10.1
30 Zn	.057	...	.305	.38	.60	.92	1.28	1.77	3.15	5.10	7.90	11.6
42 Mo	...	...	...	...	1.35	1.96	2.83	4.02	7.42	12.7	19.1	26.7
47 Ag	.056	...	.72	1.13	1.67	2.63	3.76	5.75	11.1	18.0	27.0	38.4
50 Sn	.056	.18	.78	1.16	2.00	3.00	4.35	6.30	12.1	...	...	...
74 W	...	...	2.35	3.40	5.42	8.10	2.92	3.20	5.60	8.60	13.2	19.8
78 Pt	.068	...	2.46	3.69	5.70	4.30	3.04	4.16	7.32	11.5	17.0	24.5
79 Au	...	...	2.39	3.64	5.37	3.60	3.09	4.28	7.65	...	...	...
82 Pb	.068	.50	2.47	3.78	4.32	2.0	2.93	4.62	8.46	13.9	21.9	32.7
83 Bi	.070	...	2.44	3.78	3.8	2.44	3.59	5.10	9.3	14.8	22.8	...
90 Th	.081	...	...	3.88	1.85	2.69	2.87	5.47	9.67	...	...	...

K limit

Atomic number, Element	0.500	0.600	0.700	0.800	0.900	1.00	1.10	1.32	1.40	1.76	2.25
1 H	0.45	0.44	0.51	0.57	0.63	...	...	...	...	...	...
3 Li	.245	.306	.403	...	...	...	...	...	...	...	...
6 C	.310	.412	.540	.72	1.00	1.30	2.1	3.5	4.0	7.8	15
8 O	.498	.746	1.10	1.55	2.12	2.87	...	...	...	...	...
12 Mg	1.56	...	...	...	...	...	16	...	35	63	126
13 Al	1.91	3.18	5.00	7.50	10.3	13.8	20.0	31.5	38	74	140
16 S	...	5.9	9.5	...	...	...	...	...	...	...	...
26 Fe	14.3	23.3	36.3	51.7	69.6	95	126	220	270	60	104
28 Ni	18	30	45.0	...	82	118	159	253	288	69	135
29 Cu	18.8	31.6	49.2	...	97	133	181	265	40	75	143
30 Zn	22.2	37.2	57.0	...	107	152	188	40	48	91	170
42 Mo	48.6	80.7	18.8	27.2	37.5	51	...	...	...	...	...
46 Pd	60	17.0	...	...	...	...	...	...	...	...	...
47 Ag	11.0	18.7	25.6	...	57	75	92	155	176	320	590
50 Sn	13.1	21.6	31	...	65	87	115	198	223	400	725
74 W	38.0	65.0	...	...	...	...	...	113	141	...	...
78 Pt	45.5	75.5	112	...	158	165	92	145	161	282	520
79 Au	51	77	116	...	154	110	98	148	173	300	500
82 Pb	59.3	91	133	...	140	77	100	166	185	340	...

K limit

L limit

L limit

PHOTOGRAPHIC EFFECTS OF X RAYS

X rays affect a photographic plate (or film) in much the same way as does light, except that that part, D_x, of the photographic density which is due to the radiation depends on radiation intensity, I, and the time of exposure, t, in a simpler way. The relation for monochromatic X rays is

$$D_x \equiv D - D_0 = k(1 - e^{-aIt}), \qquad 0 < D < 4 \tag{1}$$

where e is the base of natural logarithms, and k and a are constant for a given plate and given X-ray wave length. D and D_0 are the photographic densities of the exposed and unexposed parts of the plate. These densities are measurable with a photometer, photographic density being defined as the common logarithm of the reciprocal of the transmission T, i.e., density $\equiv \log_{10}(1/T)$, where T is the ratio (transmitted light)/(incident light) for a beam of light normal to the developed plate.

The limits of applicability of formula (1) probably depend on the characteristics of the plate used and on the development, as well as on the wave length of the X rays. Experimental tests indicate that the relation holds within a few per cent up to a density of at least 4, for X-ray plates, if the plate is fully developed and if the wave length of the X rays is between 0.4 and 1.1 Angstroms. Effects due to intermittency, and to the failure of the reciprocity law are negligible in the X-ray region.

NOTE: The phenomena of electron emission, photoelectric effect and contact (Volta) potential treated in the following tables are extremely sensitive to surface condition of the metal. The most consistent observations have been made in high vacua with freshly cut metal surfaces. (See Dushman, Rev. Mod. Phys., 2, 381, 1930.)

TABLE 667.—Electron Emission from Hot Solid Elementary Substances

(Most of the following is taken from Dushman, loc. cit., 1930.)

Among the free electrons within a metal some may have velocities great enough to escape the surface attraction. The number reaching the surface with velocities above this critical velocity $= N = (RT/2\pi M)^{1/2} e^{-w/rt}$ where N = no. of electrons/cm³ of metal, R the gas constant (83.14×10^6 erg-dyne), T, the absolute temperature, M, the atomic weight of an electron (.000545, $O = 16$), w the work done when a gram-molecule of electrons (6.06×10^{23} electrons or 96,500 coulombs) escape. It seems probable that this work is done against the attraction of the electron's own induced image in the surface of the conductor. When a sufficiently high + field is applied to escaping electrons so that none return to the conductor, then the saturation current has been found to follow the equation

$$i = a\sqrt{T}\cdot e^{-b/T} \text{ (Richardson's equation)}$$

assuming N and W constant with T. This is equivalent to the equation for N just given. The equation

$$I = AT^2 e^{-b_0/T} \text{ (Laue's equation)}$$

is just as valid theoretically and Dushman (Phys. Rev., 21, 623, 1923) considers A should be a universal constant (60.2 amp./cm²/deg.²/and b_0 dependent upon the emitter. The data is not accurate enough to distinguish between the two formulas. b or b_0 is a measure of the latent heat of evaporation of the electrons, i. e., the energy needed to get the electrons through the surface. While used in °K. in the above equation, it is customary to express it in volts by the relation $b_0 k = \phi_0 e$ where k = Boltzmann's constant, e, the electronic charge, and ϕ_0 is known as the work function, whence

$$\phi_0 = 8.62 \times 10^{-5} b_0 \text{ (volts)}$$

The experimental values of A do not seem to be independent of the substance.

Element	$b \times 10^{-4}$	A	$b_0 \times 10^{-4}$	ϕ_0	I_T	T	
Mo	5.26	60.2	5.15	4.44	1.6×10^{-3}	2000	Dushman, 1925
Pt	...	1.7×10^4	7.25	6.27	9.2×10^{-10}	1600	DuBridge, 1928
Ta	4.98	60.2	4.72	4.07	1.38×10^{-2}	2000	Dushman, 1925
Tn	...	60.2	3.89	3.35	4×10^{-3}	1600	Zwikker, 1926
W	...	60.2	5.240	4.52	1×10^{-3}	2000	Average
Zr	...	330	4.79	4.13	8×10^{-5}	1600	Zwikker, 1929

(Above table of best authenticated values is from Dushman, loc. cit., p. 394, 1930. His table contains values for C, Ca, Cs, Hf, Ni. See also I.C.T.)

TABLE 668.—Electron Emission from Thorium-Coated Filaments (Monomolecular), $f(\theta)$

Values given for Dushman with W filaments coated with monomolecular films of thorium. $\theta = (b_0 - b_w)/(b_{Th} - b_w)$ where b_0, b_{Th} and b_w represent values of b_0 in the emission equation for partly covered, completely covered, and pure tungsten surface.

I_0 and ϕ_0 refer to 1900°.

$\theta = 1.00$	$A_\theta = 3.0$	$b_\theta = 30{,}500$	$I_\theta = 1.166$	$\Phi_\theta = 2.63$
0.95	1.50	31,460	0.349	2.71
.72	3.74	36,570	.0594	3.15
.43	10.86	42,840	.0064	3.69
.25	15.81	47,050	.0010	4.06

TABLE 669.—Emission Current, I, Emission Efficiency I/W, Diffusion, D, I_0 for Zero Field, Completely Activated Surface, Th on W

T	I (amp./cm²)	I/W (amp./watt)	D (cm²/sec.)	E (atoms/sec./cm²	I_0
1000°	1.73×10^{-7}	2.87×10^{-7}	....	....	8.0×10^{-9}
1200	3.95×10^{-5}	2.38×10^{-5}	....	....	5.3×10^{-6}
1400	2.03×10^{-3}	5.30×10^{-4}	2.4×10^{-15}	0.445	5.4×10^{-4}
1500	1.00×10^{-2}	1.81×10^{-3}	2.2×10^{-14}	58.5	3.5×10^{-3}
1600	4.06×10^{-2}	5.24×10^{-3}	1.6×10^{-13}	4.2×10^3	1.8×10^{-2}
1700	1.40×10^{-1}	1.32×10^{-2}	9.2×10^{-13}	1.8×10^5	7.9×10^{-3}
1800	$4.28 \times$ "	3.09×10^{-2}	4.3×10^{-12}	5.2×10^6	2.9×10^{-1}
1900	1.164	6.24×10^{-2}	1.7×10^{-11}	1.0×10^8	9.5×10^{-1}
2000	2.864	1.19×10^{-1}	5.9×10^{-11}	1.5×10^9	2.8

TABLE 670.—Electron Emission from Other Than Th-Coated Filaments

Monatomic films of other rare earths (and alkaline earth metals absorbed on tungsten and molybdenum). D cm²/sec.$^{-1}$ for $T = 2000$. Q_D, heat of diffusion (g cal./g-atom), E, the rate of evaporation in atoms/cm²sec. at 2000° K. A, b_0 refer to formulas on page 547.

Emitter	A	b_0	$D \times 10^{11}$	Q_D	$E \times 10^9$
Ce-W	8.0	31,500.	95.	83,000	1450
La-W	8.0	31,500.	....	.....	....
U-W	3.2	33,000.	1.3	100,000	>Th
Yt-W	7.0	31,300.	324.	78,000	68.
Zr-W	5.0	36,500.	1820.	62,000	....
Th-W	3.0	30,500.	5.9	94,000	1.53
Th-Mo	1.5	30,000.	102000.	52,000	5400.

TABLE 671.—Photoelectric Effect

A negatively charged body loses its charge under the influence of ultra-violet light because of the escape of negative electrons freed by the absorption of the energy of the light. The light must have a wave length shorter than some limiting value λ_0 characteristic of the metal. The emission of these electrons, unlike that from hot bodies, is independent of the temperature. The relation between the maximum velocity v of the expelled electron and the frequency ν of the light is $(\frac{1}{2})mv^2 = h\nu - P$ (Einstein's equation) where h is Planck's constant (6.58×10^{-27} erg. sec.); $h\nu$ sometimes taken as the energy of a "quanta," P, the work which must be done by the electron in overcoming surface forces. $(\frac{1}{2})mv^2$ is the maximum kinetic energy the electron may have after escape. Richardson identifies the P of Einstein's formula with the w of electron emission of the preceding table. The minimum frequency ν_0 (corresponding to maximum wave length λ_0) at which the photoelectric effect can be observed is determined by $h\nu = P$. P applies to a single electron, whereas w applies to one coulomb (6.062×10^{23} electrons); therefore $w = NP = .00399\nu_0$ ergs. $\phi = (12.4 \times 10^{-5})\lambda_0$ volts. See Millikan, Proc. Nat. Acad. 2, 78, 1916; Phys. Rev. 7, 355, 1916; 4, 73, 1914; Hennings, Phys. Rev. 4, 228, 1914.

TABLE 672.—Contact (volta) Potentials

	Pt	Fe	Cu	Au	Ag	Al	Mg	Zn	Pb	Sn
SiO_2 ...	+2.22	+1.99	+1.60	+1.60	+1.42	+.93	+.93	+.45	+.16	−.30
Glass ..	+1.15	+1.15	+0.58	+0.58	+0.58	+.14	+.14	−.29	−.60	−1.14

	Cu	Cr	Ta	Mo	Ni
W	+.08	+.11	−.38	−.21	−.17

SiO_2, Glass ......Polednik, Z. Phys.............. 66, 619, 1930.
W ....Kosters, " " .... 66, 807, 1930.

(This Table Supplements Table 677.)

3	Li	3.00	13	Al	2.70	25	Mn	2.95†	36	Kr	2.35*	54	Xe	2.70*
4	Gl	2.30	14	Si	2.35	26	Fe	2.80	37	Rb	4.50	55	Cs	4.75
6	C	1.54	16	S	2.05	27	Co	2.75	38	Sr	3.90	56	Ba	4.20
7	N	1.30	17	Cl	2.10	28	Ni	2.70	47	Ag	3.55	81	Tl	4.50
8	O	1.30	18	A	2.05*	29	Cu	2.75	48	Cd	3.20	82	Pb	3.80
9	F	1.35	19	K	4.15	30	Zn	2.65	50	Sn	2.80	83	Bi	2.96
10	Ne	1.30*	20	Ca	3.40	33	As	2.52	51	Sb	2.80			
11	Na	3.55	22	Ti	2.80	34	Se	2.35	52	Te	2.65			
12	Mg	2.85	24	Cr	2.80†	35	Br	2.38	53	I	2.80			

* Outer electron shell. † Cr, "electronegative," 2.35; Mn., ditto, 2.35.

Broughall (Phil. Mag. 41, p. 872, 1921) computes in the same units from Van der Waal's constant "b" the diameters of He, N, A, Kr, and X as 2.3, 2.6, 2.9, 3.1, and 3.4. These inert elements correspond to Langmuir's completely filled successive electron shells. The corresponding atomic numbers are 2, 10, 18, 36 and 54. For Langmuir's theory see J. Am. Ch. Soc., p. 868, 1919, Science 54, p. 59, 1921.

TABLE 672.—Contact (Volta) Potentials

There has been considerable controversy over the reality and nature of the contact differences of potential between two metals. At present, due to the studies of Langmuir, there is a decided tendency to believe that this Volta difference of potential is an intrinsic property of metals closely allied to the phenomena just given in Tables 667 to 671 and that the discrepancies among different observers have been caused by the same disturbing surface conditions. The following values of the contact potentials with silver and the relative photo-sensitiveness of a few of the metals are from Henning, Phys. Rev. 4, 228, 1914. The values are for freshly cut surfaces in vacuo. Freshly cut surfaces are more electro-positive and grow more electro-negative with age. That the observed initial velocities of emission of electrons from freshly cut surfaces are nearly the same for all metals suggests that the more electro-positive a metal is the greater the actual velocity of emission of electrons from its surface.

	Ag	Cu	Fe	Brass	Sn	Zn	Al	Mg
Contact potential with Ag	0	.05	.19	.21	.27	.59	.99	1.42
Relative photo-sensitiveness	50	60	65	45	70	80	500	1000

From the equation $w = RT \log(N_A/N_B)$, where w is the work necessary per gram-molecule when electrons pass through a surface barrier separating concentrations N_A and N_B of electrons, it can be shown (Langmuir, Tr. Am. Eletroch. Soc. 29, 142, 1916, *et seq.*) that the Volta potential difference between two metals should be

$$v_1 - v_2 = \frac{1}{F}\{w_2 - w_1 + RT \log(N_A/N_B)\} = \frac{w_2 - w_1}{F} = \phi_2 - \phi_1$$

(see Table 671 for significance of symbols), since the number of free electrons in different metals per unit volume is so nearly the same that $RT \log (N_A/N_B)$ may be neglected. The contact potentials may thus be calculated from photoelectric phenomena (see Table 671 for references). They are independent of the temperature. The following table gives a summary of values of ϕ in volts obtained from the various phenomena where an electron is torn from the attraction of some surface. In the case of ionization potentials the work necessary to take an electron from an atom of metal vapor is only approximately equal to that needed to separate it from a solid metal surface.

TABLE 673.—(a) The Electron Affinity of the Elements, in Volts

Metal.	Contact. (Henning.)	Thermionic. (Langmuir.)	Photo-electric and contact. (Millikan.)	Photo-electric. (Richardson)	Miscellaneous.	Single-line spectra.	Adjusted mean.
Tungsten	—	4.52	—	—	—	—	4.52
Platinum	—	—	—	4.3	4.45	—	4.4?
Tantalum	—	4.31	—	—	—	—	4.3
Molybdenum	—	4.31	—	—	—	—	4.3
Carbon	—	4.14	—	—	—	—	4.1
Silver	4.05	—	—	—	—	—	4.1
Copper	(4.0)	—	—	4.1	—	—	4.0
Bismuth	—	—	—	3.7	—	—	3.7
Tin	3.78	—	—	3.5	—	—	3.8
Iron	3.86	3.2?	—	—	—	—	3.7
Zinc	3.46	—	—	3.4	—	4.04	3.4
Thorium	—	3.36	—	—	—	—	3.4
Aluminum	3.06	—	—	2.8	—	—	3.0
Magnesium	2.63	—	—	3.2	—	4.35	2.7
Titanium	—	2.4?	—	—	—	—	2.4
Lithium	—	—	2.35	—	—	1.85	2.35
Sodium	—	—	1.82	2.1	—	2.11	1.82

(*b*) It should not be assumed that all the emf of an electrolytic cell is contact emf. Its emf varies with the electrolyte, whereas the contact emf is an intrinsic property of a metal. There must be an emf between the two electrodes of such a cell dependent upon the concentration of the electrolyte used. The following table gives in its first line the electrode potential e_h of the corresponding metals (in solutions of their salts containing normal ion concentration) on assumption of no contact emf at the junction of the metals. The second line, $\phi - e_h - 3.7$ volts, gives an idea of the electrode potentials (arbitrary zero) exclusive of contact emf.

Metal	Ag	Cu	Bi	Sn	Fe	Zn	Mg	Li	Na
e_h	+0.80	+0.34	+0.20	−0.10	−0.43	−0.76	−1.55	−3.03	−2.73
$\phi - e_h - 3.7$	−0.40	+0.04	+0.20	−0.20	−0.43	−0.40	−0.55	−1.65	−0.85

TABLE 674.—Molecular Velocities

The probability of a molecular velocity x is $(4/\sqrt{\pi})x^2e^{-x^2}$, the most probable velocity being taken as unity. The number of molecules at any instant of speed greater than c is $2N(hm/\pi)^{\frac{1}{2}}\left\{\int_c^\infty e^{-hmc^2}\,dc + ce^{-hmc^2}\right\}$ (see table), where N is the total number of molecules. The mean velocity G (sq. rt. of mean sq.) is proportional to the mean kinetic energy and the pressure which the molecules exert on the walls of the vessel and is equal to $15{,}800\sqrt{T/m}$ cm/sec, where T is the absolute temperature and m the molecular weight. The most probable velocity is denoted by W, the average arithmetical velocity by Ω.

$$G = W\sqrt{3/2} = 1.225W; \qquad \Omega = W\sqrt{4/\pi} = 1.128W; \qquad G = \Omega\sqrt{3\pi/8} = 1.086\Omega.$$

The number of molecules striking unit area of inclosing wall is $(1/4)N\Omega$ (Meyer's equation), where N is the number of molecules per unit volume; the mass of gas striking is $(1/4)\rho\Omega$ where ρ is the density of the gas. For air at normal pressure and room temperature (20° C) this is about 14 g/cm² sec. See Langmuir, Phys. Rev. 2, 1913 (vapor pressure of W) and J. Amer. Ch. Soc. 37, 1915 (Chemical Reactions at Low Pressures), for fertile applications of these latter equations. The following table is based on Kinetic Theory of Gases, Dushman, Gen. Elec. Rev. 18, 1915, and Jeans, Dynamical Theory of Gases, 1916.

Gas.	Molecular weight.	Sq. rt. mean sq. $G \times 10^{-2}$ cm/sec.			Arithmetical average velocity, $\Omega \times 10^{-2}$ cm/sec.							
		273°	293°	373°	223°	273°	293°	373°	1000°	1500°	2000°	6000°
Air	28.96	485	502	567	404	447	463	522	855	1047	1209	2094
Ammonia	17.02	633	655	740	527	583	604	681	1115	1367	1577	2734
Argon	39.88	413	428	483	344	381	395	445	729	892	1030	1784
Carbon monoxide	28.00	493	511	576	410	454	471	531	870	1065	1230	2130
Carbon dioxide	44.00	393	408	459	327	362	376	434	694	850	981	1700
Helium	4.00	1311	1358	1533	1092	1208	1252	1412	2300	2840	3270	5680
Hydrogen	2.01	1838	1904	2149	1534	1696	1755	1980	3241	3970	4583	7940
Krypton	82.92	286	296	335	238	263	272	308	502	618	712	1236
Mercury	200.6	184	191	215	154	170	176	199	325	398	459	796
Molybdenum	96.0	—	—	—	—	—	—	—	469	575	664	1150
Neon	20.2	584	605	683	486	538	557	629	1030	1260	1460	2520
Nitrogen	28.02	493	511	577	410	454	471	531	869	1064	1229	2128
Oxygen	32.00	461	478	539	384	425	440	497	813	996	1150	1992
Tungsten	184.0	—	—	—	—	—	—	—	339	416	480	832
Water vapor	18.02	615	637	720	512	566	587	662	1084	1317	1533	2634
Xenon	130.2	228	236	267	190	210	218	246	400	493	570	986

Free electron, molecular weight = 1/1835 when $H = 1$; $G = 1.114 \times 10^7$ at 0° C and $\Omega = 1.026 \times 10^7$ at 0° C.

TABLE 675.—Molecular Free Paths, Collision Frequencies, and Diameters

The following table gives the average free path L derived from Boltzmann's formula μ $(.3502\rho\Omega)$, μ being the viscosity, ρ the density, and from Meyer's formula $\mu(.3097\rho\Omega)$. Experimental values (Verh. d. Phys. Ges. 14, 596, 1912; 15, 373, 1913) agree better with Meyer's values, although many prefer Boltzmann's formula. As the pressure decreases, the free path increases, at one bar (ordinary incandescent lamp) becoming 5 to 10 cm. The diameters may be determined from L by Sutherland's equation $\{1.402/\sqrt{2\pi NL(1 + C/T)}\}^{\frac{1}{2}}$, N being the number of molecules per unit vol. and C Sutherland's constant; from van der Waal's b, $\{3b/2NV\pi\}^{\frac{1}{3}}$; from the heat conductivity k, the specific heat at constant volume c_v, $\{.146\rho Gc_v/Nk\}^{\frac{1}{2}}$ (Laby and Kaye); a superior limit from the maximum density in solid and liquid states (Jeans, Sutherland, 1916) and an inferior limit from the dielectric constant D, $\{(D-1)2/\pi N\}^{\frac{1}{3}}$, or the index of refraction n, $\{(n^2-1)2/\pi N\}^{\frac{1}{3}}$. The table is derived principally from Dushman, *l.c.*

Gas.	$L \times 10^6$ (cm) Average free path.*			Collision frequency. $\Omega/L \times 10^{-6}$ 20° C *	$10^8 \times$ Molecular diameters (cm):				
	Boltzmann.		Meyer.		From L (viscosity) μ	From van der Waal's b	From heat conductivity k	Limiting	
	0° C	20° C	20° C					Max. density ρ	Min. D or n
Ammonia	5.92	6.60	5.83	9150	2.97	3.08	—	—	—
Argon	8.98	9.88	8.73	4000	2.88	2.94	2.86	2.87	2.66
Carbon monoxide	8.46	9.23	8.16	5100	3.19	3.12	—	3.27	2.74
" dioxide	5.56	6.15	5.44	6120	3.34	3.23	3.40	3.35	2.90
Helium	25.25	27.45	33.10	4540	1.90	2.65	2.30	1.98	1.92
Hydrogen	16.00	17.44	15.40	10060	2.40	2.34	2.32	2.40	2.17
Krypton	9.5	—	—	—	—	(3.69)	3.14	3.35	(2.70)
Mercury	—	(14.70)	(13.0)	—	—	3.01	—	—	—
Nitrogen	8.50	9.29	8.21	5070	3.15	3.15	3.53	3.23	2.95
Oxygen	9.05	9.93	8.78	4430	2.98	2.92	—	2.99	2.71
Xenon	5.6	—	—	—	—	4.02	3.42	3.55	(3.18)

* Pressure = 10^6 bars = 10^6 dynes ÷ cm² = 75 cm Hg.

TABLE 676.—Cross-Sections and Lengths of Some Organic Molecules

According to Langmuir (J. Am. Ch. Soc. 38, 2221, 1916) in solids and liquids every atom is chemically combined to adjacent atoms. In most inorganic substances the identity of the molecule is generally lost, but in organic compounds a more permanent existence of the molecule probably occurs. When oil spreads over water evidence points to a layer a molecule thick and that the molecules are not spheres. Were they spheres and an attraction existed between them and the water, they would be dissolved instead of spreading over the surface. The presence of the −COOH, −CO or −OH groups generally renders an organic substance soluble in water, whereas the hydrocarbon chain decreases the solubility. When an oil is placed on water the −COOH groups are attracted to the water and the hydrocarbon chains repelled but attracted to each other. The process leads the oil over the surface until all the −COOH groups are in contact if possible. Pure hydrocarbon oils will not spread over water. Benzene will not mix with water. When a limited amount of oil is present the spreading ceases when all the water-attracted groups are in contact with water. If weight w of oil spreads over water surface A, the area covered by each molecule is AM/wN where M is the molecular weight of the oil (O = 16), N, Avogadro's constant. The vertical length of a molecule $l = M/a\rho N = W/\rho A$ where ρ is the oil density and a the horizontal area of the molecule.

Substance.	Cross section in cm² × 10¹⁶	l in cm (length) × 10⁸	Substance.	Cross section in cm² × 10¹⁶	l in cm (length) × 10⁸
Palmitic acid $C_{15}H_{31}COOH$	24	19.6	Cetyl alcohol $C_{16}H_{33}OH$	21	21.9
Stearic acid $C_{17}H_{35}COOH$	24	21.8	Myricyl alcohol $C_{30}H_{61}OH$	29	35.2
Cerotic acid $C_{25}H_{51}COOH$	25	29.0	Cetyl palmitate $C_{15}H_{31}COOC_{16}H_{33}$	21	44.0
Oleic acid $C_{17}H_{33}COOH$	48	10.8	Tristearin $(C_{18}H_{35}O_2)_3C_3H_5$	69	23.7
Linoleic acid $C_{17}H_{31}COOH$	47	10.7	Trielaidin $(C_{18}H_{33}O_2)_3C_3H_5$	137	11.9
Linolenic acid $C_{17}H_{29}COOH$	66	7.6	Triolein $(C_{18}H_{33}O_2)_3C_3H_5$	145	11.2
Ricinoleic acid $C_{17}H_{32}(OH)COOH$	90	5.8	Castor oil $(C_{17}H_{32}(OH)COO)_3C_3H_5$	280	5.7
			Linseed oil $(C_{17}H_{31}COO)_3C_3H_5$	143	11.0

TABLE 677.—Size of Diffracting Units in Crystals ¶

The use of crystals for the analysis of X-rays leads to estimates of the relative sizes of molecular magnitudes. The diffraction phenomenon is here not a surface one, as with gratings, but one of interference of radiations reflected from the regularly spaced atomic units in the crystals, the units fitting into the lattice framework of the crystal. In cubical crystals {100} this framework is built of three mutually perpendicular equidistant planes whose distance apart in crystallographic parlance is d_{100}. This method of analysis from the nature of the diffraction pattern leads also to a knowledge of the structure of the various atoms of the crystal. See Bragg and Bragg, X-rays and Crystal Structure, 1918.

Crystal.	Elementary diffracting element.	Side of cube.	Molecules or atoms in unit cube.
		cm	
KCl	Face-centered cube *	6.28×10^{-8}	4 molecules
NaCl	" " "	5.628×10^{-8}	"
ZnS	" " " †	5.43×10^{-8}	"
CaF_2	" " " ‡	5.46×10^{-8}	"
FeS_2	" " " §	5.38×10^{-8}	"
Fe	Body-centered cube	2.86×10^{-8}	2 atoms
Al	Face-centered cube	4.05×10^{-8}	4 "
Na	Body-centered cube	4.30×10^{-8}	2 "
Ni	" "	2.76×10^{-8}	2 "
"	Face-centered cube	3.52×10^{-8}	4 "

* Each atom is so nearly equal in diffracting power (atomic weight) in KCl that the apparent unit diffracting element is a cube (simple) of $\frac{1}{8}$ this size. Elementary body-centered cube, — atom at each corner, one in center; e.g., Fe, Ni (in part), Na, Li? Elementary face-centered cube, — atom at each corner, one in center of each face; e.g., Cu, Ag, Au, Pb, Al, Ni (in part), etc. Simple cubic lattice, — atom in each corner. Double face-centered cubic or diamond lattice — C (diamond); Si, Sb, Bi, As?, Te?.

† Diamond lattice. ‡ Cubic-holohedral. § Cubic-pyritohedral.

Metals taken from Hull, Phys. Rev. 10, p. 661, 1917

¶ See page 543 for best values of calcite and rock-salt grating spaces.

Note: — (Hull, Science 52, 227, 1920). **Ca**, face-centered cube, side 5.56 A, each atom 12 neighbors 3.93 A distant. **Ti**, centered cube, cf. Fe, side 3.14 A, 8 neighbors 2.72 A. **Zn**, 6 nearest neighbors in own plane. 2.67 A, 3 above, 3 below, 2.92 A. **Cd**, cf. Zn, 2.98 A, 3.30 A. **In**, face-centered tetragonal, 4 nearest 3.24 A, 4 above, 4 below, 3.33 A. **Ru**, cf. Zn, 2.69 A, 2.64 A. **Pd**, face-centered cube, side 3.92 A, 12 neighbors. 2.77 A. **Ta**, centered cube, side 3.27 A, 8 neighbors 2.83 A. **Ir**, face-centered cube, side 3.80 A, 12 neighbors, 2.69 A (A = 10^{-8} cm).

Note: — (Bragg, Phil. Mag. 40, 169, 1920). Crystals empirically considered as tangent spheres of diameter in table, atom at center of sphere. When lattice known allows estimation of dimensions of crystal unit. Table foot of page 548 (atomic numbers, elements, diameter in Angstroms, 10^{-8} cm).

IONIC MOBILITIES AND DIFFUSIONS

The process of ionization is the removal of an electron from a neutral molecule, the molecule thus acquiring a resultant + charge and becoming a + ion. The negative carriers in all gases at high pressures, except inert gases, consist for the most part of carriers with approximately the same mobilities as the + ions. The negative electrons must, therefore, change initially to ions by union with neutral molecules.

The mobility, U, of an ion is its velocity in cm/sec. for an electrical field of one volt per cm. The rates of diffusion, D, are given in cm³/sec. $U = DP/Ne$, where P is the pressure, N, the number of molecules per unit volume of a gas and e the electronic charge.

Nature of the gas and the mobilities: (1) The mobilities are approximately proportional to the inverse sq. rts. of the molecular weights of the permanent gases; better yet when the proportionality is divided by the 4th root of the dielectric constant minus unity; (2) The ratio $U+/U-$ seems to be greater than unity in all the more electro-negative gases.

Mobilities of Gaseous Mixtures: Three types: (1) Inert gases have high mobilities; small traces of electro negative gases make values normal. (2) Mixed gases: lowering of mobilities is greater than would be expected from simple law of mixture. (3) Abnormal changes produced by addition of small quantities of electro-negative gases:

	$U+$	$U-$	
e.g.: normal mobility	= 1.37	1.80	Wellisch, Pr.
6 mm C_2H_5Br gave	1.37	1.80	Roy. Soc. 82A,
6 mm C_2H_3I "	1.37	1.80	p. 500, 1909.
10 mm C_2H_5OH "	0.91	1.10	
9 mm C_3H_6O "	1.15	1.37	

Temperature Coefficient of Mobility: There is no decided change with the temperature.

Pressure Coefficient of Mobility: Mobility varies inversely with the pressure in air from 100 to 1/10 atmosphere for − ion, to 1/1000, for + ion; below 1/10 atmosphere all observers agree that the negative ion in air increases abnormally rapidly.

Free Electrons: In pure He, Ar, and N, the negative carriers have a high mobility and are, in part at any rate, free electrons; electrons become appreciable in air at 10 cm pressure.

TABLE 678.—Ionic Mobilities

Dry gas.	Mobilities. +	Mobilities. −	$K-1$	Observer.	Dry gas.	Mobilities. +	Mobilities. −	$K-1$	Observer.
H	6.70	7.95	.000273	Zeleny	Nitrous oxide	0.82	0.90	.00107	Wellisch
He	5.09	6.31	.000074	Franck	Ethyl alcohol	0.34	0.27	.00940	"
Ar	1.37	—	.000100	"	CCl_4	0.30	0.31	.00426	"
N	1.27	—	.000590	"	Ethyl chloride	0.33	0.31	.01550	"
O	1.36	1.80	.000540	Zeleny	Ethyl ether	0.29	0.31	.00742	"
CO_2	0.81	0.85	.000960	Wellisch	Methyl bromide	0.29	0.28	.01460	"
NH_3	0.74	0.80	.00770	"	Ethyl formate	0.30	0.31	.00870	"
Air	1.40	1.78	.000590	Mean	Ethyl iodide	0.17	0.16	—	"

Franck, Jahr. d. Rad. u. Elek. 9, p. 2, 1912; Wellisch, Pr. Roy. Soc. 82A, p 500, 1909. The following values are from Yen, Pr. Nat. Acad 4, 19 8.

	H_2	N_2	Air	SO_2	C_5H_{12}	C_2H_6O	C_2H_4O	C_2H_5Cl	CH_3I	C_2H_5I
$U+$	5.54	1.30	1.37	.412	.385	.363	.307	.304	.216	1.81
$U-$	8.45	1.80	1.81	.414	.451	.373	.331	.317	.226	1.81
$U-/U+$	1.53	1.38	1.34	1.00	1.17	1.03	1.07	1.04	1.05	1.00

TABLE 679.—Diffusion Coefficients

The following table gives the observed and computed ($D = 300UP/Ne$ = very nearly $0.0236U$) values of the diffusion coefficients. The diffusion coefficients are given for some neutral molecules as actually determined for some gases into gases of nearly equal molecular weight. Table taken from Loeb, "The Nature of the Gaseous Ion," J. Franklin Inst. 184, p. 775, 1917.

Gas, diffusing.	Gas diffused into	D molecules.	$U+$	$D+$ for ions. Computed.	$D+$ for ions. Observed.
Ar	He	0.706	5.09	1.20	—
H_2	N_2	.739	6.02	0.143	0.123
Air	O_2	.178	1.35	0.0319	0.028
O_2	N_2	.171	1.27	.0299	.025
CO_2	N_2O	1.5-1.0	.82	.0193	.023 *
CO_2	CO	1.31	.81	.0193	—
C_2H_5OH	CO_2	0.0693	.34	.00805	—
Air	Ethyl acetate	.093	.30 †	.0071	—
H_2O	Air	.246	1.35	.0319	—
NH_3	NH_3	.100 ‡	0.74	.0174	—

* CO_2 into CO_2. † Ethyl formate. ‡ Estimated.

COLLOIDS

TABLE 680.—General Properties of Colloids

For methods of preparing colloids, see The Physical Properties of Colloidal Solutions, Burton, 1916; for general properties, see Outlines of Colloidal Chemistry, Journ. Franklin Inst. 185, p. 1, 1918 (contains bibliography).

The colloidal phase is conditioned by sufficiently fine division (1×10^{-4} to 10^{-7} cm). Colloids are suspensions (in gas, liquid, solid) of masses of small size capable of indefinite suspension; suspensions in water, alcohol, benzole, glycerine, are called hydrosols, alcosols, benzosols, glycerosols, respectively. The suspended mass is called the disperse phase, the medium the dispersion medium.

Colloids fall into 3 quite definite classes: 1st, those consisting of extremely finely divided particles (Cu, Au, Ag, etc.) capable of more or less indefinite suspension against gravity, in equilibrium of somewhat the same aspect as the gases of the atmosphere, depending as in the Brownian movement upon the bombardment of the molecules of the medium; 2nd, those resisting precipitation (hæmoglobin, etc.) probably because of charged nuclei and which may be coagulated and precipitated by the neutralization of the charges; 3rd, colloidal as distinguished from the crystalloidal condition, the colloid being very slowly diffusible and incapable (unlike crystalloids) of penetrating membranes (gelatine, silicic acid, caramel, glue, white of egg, gum, etc.).

Lyophile, marked affinity between two phases. c.f., hydrophile.
Lyophobe, " " absent. c.f., hydrophobe.
Smallest particle of Au observed by Zsigmody (ultramicroscope) 1.7×10^{-7} cm.
" " visible in ordinary microscope about 2.5×10^{-5} cm.
" " " " ultramicroscope, with electric arc 15×10^{-7} cm.
" " " " " with direct sunlight 1×10^{-7} cm.

Viscosity of Lyophile Sols

Gelatine	20° C., concentration	1, viscosity	0.021
Silicic acid	" , "	1.00, "	0.016
" "	" , "	2.00, "	0.035

TABLE 681.—Molecular Weights of Colloids

Determined from diffusion		Determined from freezing point		Particle wt. Svedberg	
Gum arabic	1750	Glycogen (162)*	1625	Egg albumen	34500
Tannic acid (322)*	2730	Tungstic acid (250)*	1750	Hemoglobin	68100
Egg albumen	7420	Gum	1800	Phycoerthin	20800
Caramel	13200	Albumose	2400		
(Due to Graham)		Ferric hydrate (107)*	6000		
		Egg albumen	14000		
		Starch (162)*	25000		

* Formula weight.

TABLE 682.—Brownian Movement

The Brownian movement is a microscopically observed agitation of colloidal particles. It is caused by the bombardment of them by the molecules of the medium and may be used to determine the value of Avogadro's number. Perrin, Chaudesaignes, Ehrenhaft and De Broglie found, respectively, 70, 64, 63 and 64×10^{22} as the value of this constant. The following table indicates the size and the dependence of this movement on the magnitude of the particles.

Material.	Diameter $\times 10^5$ cm	Medium.	Temp. °C	Velocity $\times 10^5$ cm/sec.	Observer.
Dust particles	2.0	Water	—	none	Zsigmody
Gold	0.35	"	20?	200.	"
Gold	0.1	"	"	280.	"
Gold	0.06	"	"	700.	"
Platinum	.4 to .5	Acetone	18	3900.	Svedberg, 1906–9
Platinum	" " "	Water	20	3200.	"
Rubber emulsion	10.	"	17	124.	Henri, 1908
Mastic	10.	"	20?	1.55	Perrin, Dabrowski, 1909.
Gamboge	4.5	"	20	2.4	Chaudesaignes, 1908.
"	2.13	"	"	3.4	"

The movement varies inversely as the size of the particles; in water, particles of diameter greater than 4μ show no perceptible movement; when smaller than $.1\mu$, lively movement begins, while at 10 $m\mu$ the trajectories amount up to $20 m\mu$.

COLLOIDS

TABLE 683.—Adsorption of Gas by Finely Divided Particles

Fine division means great surface per unit weight. All substances tend to adsorb gas at surface, the more the higher the pressure and the lower the temperature. Since different gases vary in this adsorption, fractional separation is possible. Pt black can absorb 100 vols. H_2, 800 vols. O_2, Pd 3000 vols. H_2. In gas analysis Pd, heated to 100°, is used to remove H_2 (higher temperature used for faster adsorption, will take more at lower temperature). Pt can dissolve several vols. of H_2, Pd. nearly 100 at ordinary temperatures; but it seems probable that the bulk of the 100 vols. of H_2 taken by Pt and the 3000 by Pd must be adsorbed. In 1848 Rose found the density 21 to 22 for Pt foil, but 26 for precipitated Pt.

The film of adsorbed air entirely changes the behavior of very small particles. They flow like a liquid (cf. fog). With substances like carbon black as little as 5 per cent of the bulk is C; a liter of C black may contain 2.5 liters of air. Mitscherlich calculated that when CO_2 at atmospheric pressure, 12° C, is adsorbed by boxwood charcoal, it occupies 1/56 original vol. Apparent densities of gases adsorbed at low temperatures by cocoanut charcoal are of the same order (sometimes greater) as liquids.

Cm³ of Gas Adsorbed by a Cm³ of Synthetic Charcoal (corrected to 0° C, 76 cm?) (Hemperl and Vater).

° C	H_2	Ar	N_2	O_2	CO	CO_2	NO	N_2O
+20°	7.3	12.6	21.0	25.4	26.8	83.8	103.6	109.4
−78	19.5	92.6	107.4	122.4	139.4	568.4	231.3	330.1
−185	284.7	—	632.2	—	697.0	—	—	—
	CH_4	C_2H_6	C_2H_4	C_2H_2	NH_3	H_2S	Cl_2	SO_2
+20°	41.7	119.1	139.2	135.8	197.0	213.0	304.5	337.8
−78	174.3	275.5	360.7	488.5	—	—	—	—

Cm³ of Gas Adsorbed by a Cm³ of Cocoanut Charcoal (corrected to 0° C, 76 cm) (Dewar).

° C	He	H_2	N_2	O_2	CO	Ar
0°	2	4	15	18	21	12
−185	15	135	155	230	190	175

See Langmuir, J. Am. Ch. Soc. 40, 1361, 1918; Richardson, 39, 1829, 1916.

TABLE 684.—Heats of Adsorption

Adsorber.	Amylene.	Water.	Acetone.	Methyl alcohol.	Ethyl alcohol.	Aniline.	Amyl alcohol.	Ethyl ether.	Chloroform.	Benzene.	Carbon disulphide.	Carbon tetrachloride.	Hexane.
Fuller's earth *	57.1	30.2	27.3	21.8	17.2	13.4	10.9	10.5	8.4	4.6	4.6	4.2	3.9
Bone charcoal *	—	18.5	19.3	17.6	16.5	—	10.6	—	14.0	11.1	8.4	13.9	8.9
Kaolin *	78.8	—	—	27.6	24.5	—	20.4	—	15.7	9.9	9.9	9.4	7.2
Fuller's earth †	—	.683	.684	.679	—	—	—	—	.611	.610	.621	.625	—

* Small calories liberated when 1 g of the adsorbent is added to a relatively large quantity of the liquid.
† Volume adsorbed from saturated vapor by 1 g of fuller's earth.
Gurvich, J. Russ. Phys. Ch. Soc. 47, 805, 1915.

TABLE 685.—Molecular Heats of Adsorption and Liquefaction (Favre)

Adsorber.	Gas.	Molecular heats of adsorption.	Molecular heats of liquefaction.	Adsorber.	Gas.	Molecular heats of adsorption.	Molecular heats of liquefaction.
Platinum	H_2	46200	—	Charcoal	SO_2	10000–10900	5600
Palladium	H_2	18000	—	"	HCl	9200–10200	(3600)
Charcoal	NH_3	5900–8500	(5000)	"	HBr	15200–15800	(4000)
"	CO_2	6800–7800	6250	"	HI	21000–23000	(4400)
"	N_2O	7100–10900	4400				

TABLE 686.—Transmission of Solar Radiation by Earth's Atmosphere

(Kimball, Monthly Weath. Rev., 56, 393, 1928; 58, 43, 1930.)

Upper curves give transmission (sea-level) by the general scattering by dust-free moist air summed over all wave lengths (w = precipitable water in beam); lower curves, the added fractional depletion in the selectively absorbing water-vapor bands. No allowance is indicated for dust. (See also Table 767.)

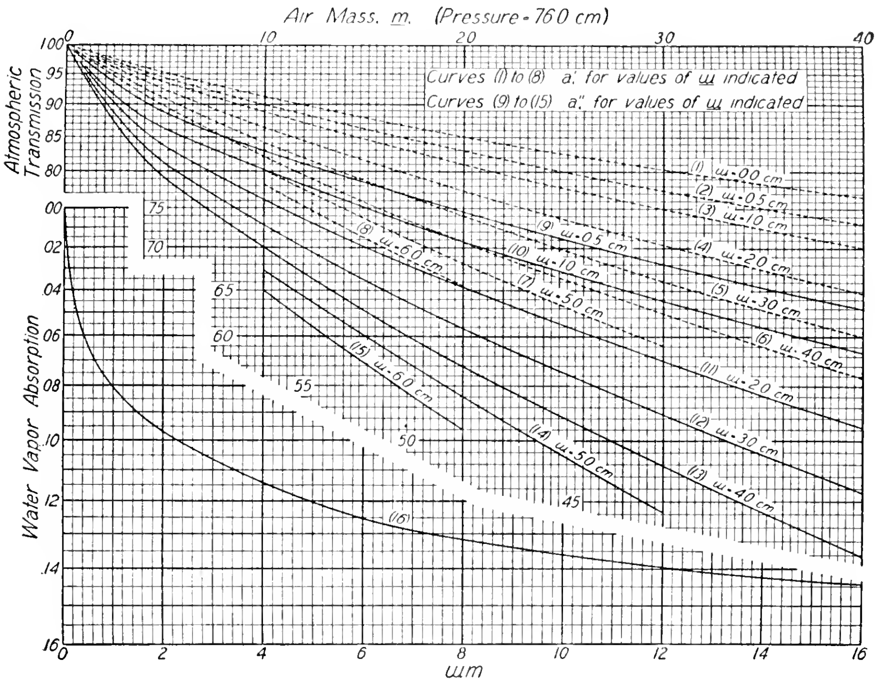

TABLE 687.—Ultra-Violet Solar Radiation at Earth's Surface

Average ultra-violet solar radiation of wave lengths <313 mμ on the clearest days in Washington during 1930-31. Data in g-cal./cm²/min. × 10⁵ (Coblentz, Stair, Bur. Standards Journ. Research, 6, 971, 1931).

	1930: Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1931: Jan.	Feb.
9 a. m.	0	3	12	22	35	41	42	41	33	16	2	0	0	1
10 "	11	24	37	49	58	63	63	59	50	35	21	11	11	29
11 "	23	37	49	60	70	76	76	71	61	48	32	19	22	42
12 noon	30	43	57	67	76	82	81	76	66	53	38	22	30	51

0.0008 cal./cm²/min. = 56 microwatts. Data are also given for greater elevations. At high elevations the spectrum quality of the u.-v. region is richer in the shorter wave lengths than at sea-level; but owing to sky-scattering, the total amount of u.-v. light less than 313 mμ at sea-level, on the clearest days, is almost as large as at high elevations.

RELATIVE INTENSITY OF SOLAR RADIATION

TABLE 688.—Mean intensity J for 24 hours of solar radiation on a horizontal surface at the top of the atmosphere and the solar radiation A, in terms of the solar radiation, A_0, at earth's mean distance from the sun.

Date.	Motion of the sun in longitude.	Relative Mean Vertical Intensity $\left(\frac{J}{A_0}\right)$. Latitude North. 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	$\frac{A}{A_0}$.
Jan. 1	0.99°	0.303	0.265	0.220	0.169	0.117	0.066	0.018				1.0335
Feb. 1	31.54	.312	.282	.244	.200	.150	.100	.048	0.006			1.0288
Mar. 1	59.14	.320	.303	.279	.245	.204	.158	.108	.056	0.013		1.0173
Apr. 1	89.70	.317	.319	.312	.295	.269	.235	.195	.148	.101	0.082	1.0009
May 1	119.29	.303	.318	.330	.329	.320	.302	.278	.253	.255	.259	0.9841
June 1	149.82	.287	.315	.334	.345	.349	.345	.337	.344	.360	.366	0.9714
July 1	179.39	.283	.312	.333	.347	.352	.351	.345	.356	.373	.379	0.9666
Aug. 1	209.94	.294	.316	.330	.334	.330	.318	.300	.282	.295	.300	0.9709
Sept. 1	240.50	.310	.318	.316	.305	.285	.256	.220	.180	.139	.140	0.9828
Oct. 1	270.07	.317	.308	.289	.261	.225	.183	.135	.084	.065		0.9995
Nov. 1	300.63	.312	.286	.251	.211	.164	.114	.063	.018			1.0164
Dec. 1	330.19	.304	.267	.224	.175	.124	.072	.024				1.0288
Year....		0.305	0.301	0.289	0.268	0.241	0.209	0.173	0.144	0.133	0.126	

Average annual solar energy received per square dekameter of horizontal surface in kilowatt hours. U. S.: Lincoln, 160,906; Mt. Weather, 148,824; Washington, 145,403; New York, 106,460; Chicago, 97,856. Other countries: Toronto, 139,523; Johannesburg, 175,696; Davos Platz, 174,043; So. Kensington, 78,569; Stockholm, 79,267. (Kimball, Monthly Weather Rev., Apr. 1927.)

TABLE 689.—Mean Monthly and Yearly Temperatures

Mean temperatures of a few selected American stations, also of a station of very high, two of very low temperature, and one of very great and one of very small range of temperature.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1 Hebron-Rama (Labr.)	−20.7	−20.9	−15.6	− 6.9	+ 0.2	+ 4.5	+ 7.6	+ 8.0	+ 4.5	− 0.8	− 6.2	−16.2	− 5.2
2 Winnipeg (Canada)	−21.6	−18.8	−11.0	+ 1.9	+10.9	+17.1	+18.9	+17.6	+11.6	+ 4.1	− 7.6	−15.7	+ 0.6
3 Montreal	−10.9	− 9.1	− 4.3	+ 4.8	+12.6	+18.3	+20.5	+19.3	+14.7	+ 7.8	− 0.2	− 7.1	+ 5.5
4 Boston	− 2.8	− 2.2	+ 1.2	+ 7.3	+13.6	+19.1	+21.8	+20.6	+16.9	+11.1	+ 4.8	− 0.5	+ 9.2
5 Chicago	− 4.8	− 2.9	+ 1.2	+ 7.9	+13.4	+19.7	+22.2	+21.6	+17.9	+11.1	+ 3.6	− 1.5	+ 9.1
6 Denver	− 2.1	+ 0.1	+ 3.8	+ 8.3	+13.6	+19.1	+22.1	+21.2	+16.6	+10.3	+ 3.3	0.0	+ 9.7
7 Washington	+ 0.7	+ 2.1	+ 5.2	+11.7	+17.7	+22.9	+24.9	+23.7	+19.9	+13.4	+ 6.9	+ 2.3	+12.6
8 Pikes Peak	−16.4	−15.6	−13.4	−10.4	− 5.3	+ 0.4	+ 4.5	+ 3.6	− 0.3	− 5.8	−11.8	−14.4	− 7.1
9 St. Louis	− 0.8	+ 1.7	+ 6.2	+13.4	+18.8	+24.0	+26.0	+24.9	+20.8	+14.2	+ 6.4	+ 2.0	+13.1
10 San Francisco	+10.1	+10.9	+12.0	+12.6	+13.7	+14.7	+14.6	+14.8	+15.8	+15.2	+13.5	+10.8	+13.2
11 Yuma	+12.3	+14.9	+18.1	+21.0	+25.1	+29.4	+33.1	+32.6	+29.1	+22.8	+16.6	+13.3	+22.3
12 New Orleans	+12.1	+14.5	+16.7	+20.6	+23.7	+26.8	+27.9	+27.5	+25.7	+21.0	+15.9	+13.1	+20.4
13 Massaua	+25.6	+26.0	+27.1	+29.0	+31.1	+33.5	+34.8	+34.7	+33.3	+31.7	+29.0	+27.0	+30.3
14 Ft. Conger (Greenl'd)	−39.0	−40.1	−33.5	−25.3	−10.0	+ 0.4	+ 2.8	+ 1.0	− 9.0	−22.7	−30.9	−33.4	−20.0
15 Werchojansk	−51.0	−45.3	−32.5	−13.7	+ 2.0	+12.3	+15.5	+10.1	+ 2.5	−15.0	−37.8	−47.0	−16.7
16 Batavia	+25.3	+25.4	+25.8	+26.3	+26.4	+26.0	+25.7	+25.9	+26.3	+26.4	+26.2	+25.6	+25.9

Lat., Long., Alt. respectively: (1) +58°.5, 63°.0 W, —; (2) + 49.9, 97.1 W, 233m.; (3) + 45.5, 73.6 W, 57m.; (4) + 42.3, 71.1 W, 38m.; (5) + 41.9, 87.6 W, 251m.; (6) +39.7, 105.0 W, 1613m.; (7) +38.9, 77.0 W, 34m.; (8) + 38.8, 105.0 W, 4308m.; (9) + 38.6, 90.2 W, 173m.; (10) +37.8, 122.5 W, 47m.; (11) + 32.7, 114.6 W, 43m.; (12) + 30.0, 90.1 W, 16m.; (13) + 15.6, 37.5 E, 9m.; (14) +81.7, 64.7 W., —; (15) + 67.6, 133.8 E, 140m.; (16) − 6.2, 106.8 E, 7m.

Taken from Hann's Lehrbuch der Meteorologie, 2'nd edition, which see for further data.

Note: Highest recorded temperature in world = 57° C in Death Valley, California, July 10, 1913.
Lowest recorded temperature in world = −68° C at Verkhoyansk, Feb. 1892.

TABLE 690.—Temperature Variation over Earth's Surface (Hann)

Latitude.	Temperatures ° C						Mean ocean temp.	Land surface %
	Jan.	Apr.	July.	Oct.	Year.	Range.		
North pole	−41.0	−28.0	−1.0	−24.0	−22.7	40.0	−1.7	—
+80°	−32.2	−22.7	+2.0	−19.1	−17.1	34.2	−1.7	20
70	−26.3	−14.0	7.3	−9.3	−10.7	33.6	+0.7	53
60	−16.1	−2.8	14.1	+0.3	−1.1	30.2	4.8	61
50	−7.2	+5.2	17.9	6.9	+5.8	25.1	7.9	58
40	+5.5	13.1	24.0	15.7	14.1	18.5	14.1	45
30	14.7	20.1	27.3	21.8	20.4	12.6	21.3	43.5
20	21.9	25.2	*28.0*	26.4	25.3	6.1	25.4	31.5
+10	25.8	*27.2*	27.0	*26.9*	*26.8*	1.4	27.2	24
Equator	*26.5*	26.6	25.7	26.5	26.3	0.9	27.1	22
−10	26.4	25.9	23.0	25.7	25.5	3.4	25.8	20
20	25.3	24.0	19.8	22.8	23.0	5.5	24.0	24
30	21.6	18.7	14.5	18.0	18.4	7.1	19.5	20
40	15.4	12.5	8.8	11.7	11.9	6.6	13.3	4
50	8.4	5.4	3.0	4.8	5.4	5.4	+6.4	2
60	3.2	—	−9.3	—	−3.2	12.5	0.0	0
70	−1.2	—	−21.0	—	−12.0	19.8	−1.3	71
80	(−4.3)	—	(−28.7)	—	(−20.6)	(24.4)	—	100
South pole	(−6.0)	—	(−33.0)	—	(−25.0)	(27.0)	—	(100)

TABLE 691.—Temperature Variation with Depth (Land and Ocean)

Table illustrates temperature changes underground at moderate depths due to surface warming (read from plot for Tiflis, Lehrbuch der Meteorologie, Hann and Süring, 1915). Below 20–30 m (nearer the surface in tropics) there is no annual variation. Increase downwards at greater depths, 0.03 ± ° C per m (1° per 35 m) l. c. At Pittsburgh, 1524 m, 49.4°, .0294 per m; Oberschlesien, 2003 m. 70°, .0294 per m; or W. Virginia, 2200 m, 70°, .034° per m (Van Orstrand). Mean value outflow heat from earth's center, 0.00000172 g-cal/cm²/sec. or 54 g-cal/cm²/year (39 Laby). Open ocean temperatures: Greatest mean annual range (Schott) 40° N, 4.2° C; 30° S, 5.1°; but 10° N, only 2.2°; 50° S, 2.9°. Mean surface temp. whole ocean (Krümmel) 17.4°; all depths, 3.9°. Below 1 km nearly isothermal with depth. In tropics, surface 28°; at 183 m, 11°, 80% all water less than 4.4°. Deep-sea (bottom) temps. range −0.5° to +2.6°. Soundings in S. Atlantic: 0 km, 18.9°; .25 km, 15°; .5 km, 8.3°; 1 km, 3.3°; 3 km, 1.7°; 4.5 km, 0.0°.

Depth, m	Temperature, centigrade.											
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
0	*1*	4	10	14	21	29	**32**	32	24	16	9	4
0.5	4	*4*	9	13	18	23	26	**28**	24	18	12	6
1.0	6	*6*	8	12	15	20	24	**26**	23	18	14	10
1.5	9	*8*	9	11	14	18	21	**23**	22	18	15	12
2.0	11	10	*10*	11	13	16	19	21	**21**	18	16	14
3.0	14	12	12	*11*	13	14	16	17	18	**18**	17	15
4.0	15	13	12	*12*	12	13	14	16	16	**17**	17	16
5.0	15	14	13	13	*13*	13	14	14	15	16	**16**	16
6.0	**15**	14	14	14	14	14	14	14	14	15	15	15

TABLES 692-694
THE EARTH'S ATMOSPHERE

TABLE 692.—Miscellaneous Data. Variation with Latitude

Optical evidence of atmosphere's extent: twilight 63 km, luminous clouds 83, meteors 200, aurora 44–360. Jeans computes a density at 170 km of 2×10^{13} molecules per cm³, nearly all H (5% He); at 810 km, 3×10^{10} molecules per cm³ almost all H. When in equilibrium, each gas forms an atmosphere whose density decrease with altitude is independent of the other components (Dalton's law, H_2O vapor does not). The lighter the gas, the smaller the decrease rate. A homogeneous atmosphere, 76 cm pressure at sea-level, of sea-level density, would be 7991 m high. Average sea-level barometer is 74 cm; corresponding homogeneous atmosphere (truncated cone) 7790 m, weighs (base, m²) 10,120 kg; this times earth's area is 52×10^{14} metric tons or 10^{-6} of earth's mass. The percentage by vol. and the partial pressures of the dry-air components at sea-level are: N_2, 78.03, 593.02 mm; O_2, 20.99, 159.52; A, 0.94, 7.144; CO_2, 0.03, 0.228; H_2, 0.01, 0.076; Ne, 0.0012, 0.009; He, 0.0004, 0.003 (Hann). The following table gives the variation of the mean composition of moist air with the latitude (Hann).

Equator	N_2 75.99	O_2 20.44	A 0.92	H_2O 2.63	CO_2 0.02
50° N.	77.32	20.80	0.94	0.92	0.02
70° N.	77.87	20.94	0.94	0.22	0.03

TABLE 693.—Variation of Percentage Composition with Altitude (Humphreys)

Computed on assumptions: sea-level temperature 11° C; temperature uniformly decreasing 6° per km up to 11 km, from there constant with elevation at −55°. J. Franklin Inst. 184, p. 388, 1917.

Height, km	Argon.	Nitrogen.	Water vapor.	Oxygen.	Carbon dioxide.	Hydrogen.	Helium.	Total pressure, mm
140	—	0.01	—	—	—	99.15	0.84	0.0040
120	—	0.19	—	—	—	98.74	1.07	0.0052
100	—	2.95	0.05	0.11	—	95.58	1.31	0.0067
80	—	32.18	0.17	1.85	—	64.70	1.10	0.0123
60	0.03	81.22	0.15	7.69	—	10.68	0.23	0.0935
50	0.12	86.78	0.10	10.17	—	2.76	0.07	0.403
40	0.22	86.42	0.06	12.61	—	0.67	0.02	1.84
30	0.35	84.26	0.03	15.18	0.01	0.16	0.01	8.63
20	0.59	81.24	0.02	18.10	0.01	0.04	—	40.99
15	0.77	79.52	0.01	19.66	0.02	0.02	—	89.66
11	0.94	78.02	0.01	20.99	0.03	0.01	—	168.00
5	0.94	77.89	0.18	20.95	0.03	0.01	—	405.
0	0.93	77.08	1.20	20.75	0.03	0.01	—	760.

TABLE 694.—Variation of Temperature, Pressure and Density with Altitude

Average data from sounding balloon flights (65 for summer, 52 for winter data) made at Trappes (near Paris), Uccle (near Brussels), Strassburg and Munich. Compiled by Humphreys, 16 to 20 m chiefly extrapolated.

Elevation, km	Summer.			Winter.		
	Temp. ° C	Pressure, mm of Hg.	Density, dry air, g/cm³	Temp. ° C	Pressure, mm of Hg.	Density, dry air, g/cm³
20.0	−51.0	44.1	0.000092	−57.0	39.5	0.000085
19.0	−51.0	51.5	.000108	−57.0	46.3	.000100
18.0	−51.0	60.0	.000126	−57.0	54.2	.000117
17.0	−51.0	70.0	.000146	−57.0	63.5	.000137
16.0	−51.0	81.7	.000171	−57.0	74.0	.000160
15.0	−51.0	95.3	.000199	−57.0	87.1	.000187
14.0	−51.0	111.1	.000232	−57.0	102.1	.000220
13.0	−51.0	129.6	.000270	−57.0	119.5	.000257
12.0	−51.0	151.2	.000316	−57.0	140.0	.000301
11.0	−49.5	176.2	.000366	−57.0	164.0	.000353
10.0	−45.5	205.1	.000419	−54.5	192.0	.000408
9.0	−37.8	237.8	.000470	−49.5	224.1	.000466
8.0	−29.7	274.3	.000524	−43.0	260.6	.000526
7.0	−22.1	314.9	.000583	−35.4	301.6	.000590
6.0	−15.1	360.2	.000649	−28.1	347.5	.000659
5.0	−8.9	410.6	.000722	−21.2	398.7	.000735
4.0	−3.0	466.6	.000803	−15.0	455.9	.000821
3.0	+2.4	528.9	.000892	−9.3	519.7	.000915
2.5	+5.0	562.5	.000942	−6.7	554.3	.000967
2.0	+7.5	598.0	.000990	−4.7	590.8	.001023
1.5	+10.0	635.4	.001043	−3.0	629.6	.001083
1.0	+12.0	674.8	.001100	−1.3	670.6	.001146
0.5	+14.5	716.3	.001157	0.0	714.0	.001215
0.0	+15.7	760.0	.001223	+0.7	760.0	.001290

760 mm = 29.921 in. = 1013.3 millibars. 1 mm = 1.33322387 millibars. 1 bar = 1,000,000 dynes; this value, sanctioned by International Meteorological Conferences, is 1,000,000 times that sometimes used by physicists.

Table 695

THE EARTH'S ATMOSPHERE

Standard Atmosphere

A standard atmosphere is defined by an altitude-temperature-pressure relation. It is an aeronautic necessity in evaluating the performance of airplanes and for the calibration of instruments. The following standard has been officially adopted by the Army Air Corps, Bureau of Standards, National Advisory Committee for Aeronautics, and the Weather Bureau. However, in the evaluation of flights made to break international records, the Fédération Aéronautique Internationale Standard Atmosphere is used. The altitude-temperature assumption is a slight modification of that proposed by Toussaint and closely approximates the average observed values of air temperature at all altitudes at latitude 40° in the United States. Adapted from M 78 (Brombacher) published by the Bur. Standards. The formulae defining this standard atmosphere follow:

Z = standard altitude. Z_{55} = altitude lower limit isothermal layer.
T = absolute temperature of air at altitude Z.
T_0 = standard sea-level temperature, 288° absolute, 15° C.
T_m = mean absolute temperature of air column below altitude Z.
T_{m55} = ditto for Z_{55}, 251.378° absolute.
p = air pressure at altitude Z. p_0, standard sea-level pressure, 760 mm.
ρ = density air at altitude Z. ρ_0, ditto sea-level, 1.2255 kg/m³.

$Z = (KT_m/T_0)\log_{10}(p_0/p)$. K is 19,413.3 for Z in meters, or 63,691.8 in feet.
$\rho = \rho_0(p/p_0)(T_0/T)$.

(1) Up to the isothermal layer (below 10,769 m):
$T = 288 - aZ$. $T_m = aZ/\log_e[T_0/(T_0 - aZ)]$.
$a = 0.0065000$ for Z in meters; 0.0019812 in feet.

(2) At the lower limit of the isothermal layer (10,769 m):
$T = 218°$ absolute or $-55°$C. Z_{55} = 35,322 feet or 10,769 meters.

(3) In the isothermal layer (above 10,769 meters):
$T_m = Z/[Z_{55}/T_{m55} + (Z - Z_{55})/218]$.

(See Nat. Adv. Comm. Aeronautics Techn. Rep., Nos. 147, 218, and 246 of the committee for further data and complete tables.)

Altitude		Pressure		Density		Temperature °C	Mean temperature °C
Meters	Feet	mm Hg	in Hg	kg/m³	lb./ft.³		
0	0	760.0	29.921	1.2255	0.07650	15.0	15.0
1000	3281	674.1	26.54	1.1120	.06942	8.5	11.7
2000	6562	596.2	23.47	1.0068	.06286	+ 2.0	8.4
3000	9842	525.8	20.70	.9094	.05678	− 4.5	5.1
4000	13123	462.3	18.20	.8193	.05115	−11.0	+ 1.8
5000	16404	405.1	15.95	.7363	.04597	−17.5	− 1.6
6000	19685	353.8	13.93	.6598	.04119	−24.0	− 5.0
7000	22966	307.9	12.12	.5896	.03681	−30.5	− 8.4
8000	26247	266.9	10.51	.5252	.03279	−37.0	−11.9
9000	29528	230.4	9.07	.4664	.02912	−43.5	−15.4
10000	32808	198.2	7.80	.4127	.02577	−50.0	−18.9
11000	36089	169.7	6.68	.3614	.02256	−55.0	−22.4
12000	39370	145.0	5.71	.3090	.01929	−55.0	−25.5
13000	42651	124.0	4.88	.2642	.01649	−55.0	−28.1
14000	45932	106.0	4.17	.2259	.01410	−55.0	−30.2
15000	49212	90.6	3.57	.1931	.01206	−55.0	−32.0
0	0	760.0	29.921	1.2255	.07651	15.0	15.0
1524	5000	632.3	24.89	1.0559	.06592	+ 5.1	10.0
3048	10000	522.6	20.58	.9048	.05649	− 4.8	+ 5.0
4572	15000	428.8	16.88	.7711	.04814	−14.7	− .1
6096	20000	349.1	13.75	.6527	.04075	−24.6	− 5.3
7620	25000	281.9	11.10	.5489	.03427	−34.5	−10.5
9144	30000	225.6	8.88	.4583	.02861	−44.4	−15.9
10668	35000	178.7	7.04	.3795	.02369	−54.3	−21.3
12192	40000	140.7	5.54	.2998	.01872	−55.0	−26.0
13716	45000	110.8	4.36	.2361	.01474	−55.0	−29.6
15240	50000	87.3	3.44	.1860	.01161	−55.0	−32.4

The following condensed tables (Maris, Terr. Mag. and Atmosph. Elec., 33, 233, 1928) of the upper atmosphere of the earth result from attempts at including further factors than usually considered. They should be taken as tentative because of approximate theory and ignorance of much necessary data for the discussion. Meteors, reflection of sound and radio waves, the aurora, ozone, ionization, and optical phenomena continually give us further probes into the upper air. The gases are uniformly mixed below a height of roughly 100 km; above 150 km each gas is in equilibrium with its own partial pressure; between these heights there is for each gas a transition from uniform mixture with the air to equilibrium with its own partial pressure at a height which depends on the temperature and previous wind currents of the atmosphere, but which averages about 110 km. Apparently above 300 km the atmosphere can not be assumed in equilibrium; the percentage of very high-energy molecules is far higher than indicated by a Maxwellian curve for thermal equilibrium.

TABLE 696.—Pressure in Dynes/cm², Summer and Winter, Day and Night (Maris)

Altitude Km	Pressure = $p \times 10^n$ dynes/cm²																	
	N_2		O_2		A		CO_2		Kr		He		H_2		Totals			
															No H_2		with H_2	
	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n
	Summer day																	
0	79	4	22	4	96	2	30	1	98	−2	40	−1	11	1	10	5	10	5
40	32	2	85	1	39	0	72	−1	39	−4	16	−3	41	−2	40	2	41	2
100	61	−1	16	−1	74	−3	24	−4	76	−7	31	−6	78	−5	78	−1	78	−1
200	11	−4	17	−5	23	−7	38	−9	53	−15	18	−8	31	−7	13	−4	13	−4
300	33	−8	14	−9	17	−12	93	−15	89	−26	56	−9	17	−7	40	−8	21	−7
	Summer night																	
0	79	4	22	4	96	2	30	1	98	−2	40	−1	11	1	10	5	10	5
40	23	2	62	1	28	0	89	−2	29	−4	12	−3	30	−2	30	2	30	2
100	39	−2	10	−2	48	−4	15	−5	48	−8	20	−7	50	−6	50	−2	50	2
200	48	−8	21	−9	56	−12	19	−14	34	−25	58	−9	15	−7	56	−8	21	−6
300	73	−14	52	−16	54	−20	16	−23	27	−42	88	−10	58	−8	88	−10	59	−8
	Winter day																	
0	79	4	22	4	96	2	30	1	98	−2	40	−1	11	1	10	5	10	5
40	22	2	60	1	27	0	86	−2	28	−4	12	−3	29	−2	29	2	29	2
100	70	−2	19	−2	85	−4	27	−5	86	−8	36	−7	89	−6	89	−2	64	−3
200	24	−7	14	−8	46	−11	24	−13	26	−23	64	−9	17	−7	26	−7	73	−8
300	12	−12	12	−14	12	−18	12	−21	51	−39	16	−9	71	−8	16	−9	30	−8
	Winter night																	
0	79	4	22	4	96	2	30	1	98	−2	40	−1	11	1	11	5	10	5
40	16	2	60	1	19	0	60	−2	20	−4	80	−4	11	−2	20	2	20	2
100	20	−2	53	−3	24	−4	76	−6	25	−8	10	−7	25	−6	25	−2	13	−3
200	12	−8	57	−10	58	−13	32	−15	17	−26	62	−9	12	−7	19	−8	14	−7
300	11	−14	86	−17	18	−21	14	−24	40	−44	87	−10	39	−8	87	−10	39	−8

TABLE 697.—Molecular Densities in Atmosphere (Maris)

Altitude Km	Number of molecules per cm³																	
	N_2		O_2		A		CO_2		Kr		He		H		Totals			
															No H_2		with H_2	
	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n
	Summer day																	
40	84	15	23	15	10	14	32	12	10	10	43	10	11	12	11	16	11	16
80	80	13	22	13	96	11	30	10	10	8	41	8	10	10	10	14	10	14
100	12	13	32	12	15	11	46	9	15	7	63	7	16	9	16	13	16	13
200	22	9	32	8	45	6	75	4	10	−1	35	5	61	6	25	9	25	9
300	64	5	28	4	33	1	18	−1	16	−12	11	5	34	6	77	5	41	6
	Summer night																	
40	73	15	20	15	89	13	28	12	91	9	38	10	94	11	94	15	94	15
80	22	13	59	12	27	11	84	9	27	7	14	8	28	9	28	13	28	13
100	12	12	33	11	15	10	48	8	15	6	63	6	16	8	16	12	16	12
200	15	6	66	4	21	2	49	−1	11	−10	18	5	48	6	18	6	66	6
300	23	0	17	−2	17	−6	52	−10	86	−29	28	4	18	6	28	4	19	6
	Winter day																	
40	67	15	18	15	82	13	26	12	84	9	34	10	86	11	86	15	86	15
80	29	13	78	12	35	11	11	10	36	7	15	8	37	9	37	13	37	13
100	20	12	54	11	25	10	78	8	26	6	10	7	26	8	26	12	26	12
200	69	6	39	5	13	3	71	0	75	−10	18	5	49	6	74	6	12	7
300	36	1	34	−1	35	−5	35	−8	15	−25	45	4	21	6	45	4	21	6
	Winter night																	
40	51	15	14	15	62	13	20	11	63	9	26	10	65	11	65	15	65	15
80	14	13	34	12	15	11	48	9	16	7	65	7	16	9	17	13	17	13
100	65	11	17	11	79	9	25	8	81	5	33	6	83	7	83	11	83	11
200	39	5	19	4	19	1	10	−1	57	−13	20	5	39	6	61	5	45	6
300	36	−1	28	−3	58	−8	46	−11	13	−30	23	4	13	6	23	4	13	6

TABLE 698.—Geopotential, Dynamic Heights

The "*geopotential*" or "*gravity potential*" of a point is its potential energy relative to sea-level of a unit-mass situated at the point.

In comparisons of vertical positions in dynamical meteorology, advantages result by giving the heights above sea-level in terms of the potential energy possessed by a unit-mass at these positions. The use of geopotential for heights is better realized in that surfaces of equal geopotential are identical with horizontal or level surfaces, and, due to the geographical variation of gravity, are not surfaces equally distant from sea-level.

Heights measured thus are called "dynamic heights." Defined more precisely, geopotential is

$$\Gamma = -\int_0^h g\,dh \tag{1}$$

where Γ = geopotential in absolute units, g = acceleration of gravity in meters, h = geometric height above sea-level in meters.

Γ has the dimensional formula $[L^2 T^{-2}]$, and is expressed in absolute units, the "geodecimeter" when g is expressed in m/sec.^{2}, and h in meters. The derived unit adopted by the Commission Internationale de la Haute Atmosphère is the "dynamic meter" H_d, 10 m^2/sec.^{2}, after Prof. V. Bjerknes[1]. Then H_d = dynamic height (geopotential in dynamic meters) is

$$H_d = -(1/10)\int_0^h g\,dh \tag{2}$$

Helmert's equation (3) is substituted in (2),

$$g = -(g_\phi - 0.000003086\,h), \text{ where,} \tag{3}$$

g_ϕ = g at latitude ϕ sea-level, below given point (in m/sec.^{2}), g = acceleration of gravity at point in m/sec.^{2}, h = geometric height of point above sea-level in meters. (2) may then be integrated, giving

$$H_d = [g_\phi/10]h - 1.543 \times 10^{-7}h^2. \tag{4}$$

The following table results from (4) using g_ϕ computed from the U. S. Coast and Geodetic Survey formula:

$$g_\phi = 9.78039\,(1 + 0.005294 \sin^2\phi - 0.000007 \sin^2 2\phi)$$

Neglecting the h^2 term, $H_d = 0.98\,h$, approximately, whence, $h = 1.02\,H_d$, approximately; substituting this in (4) for the h^2 term we have $h = (10/g_\phi)H_d + (10/g_\phi)1.543(1.02)^2 10^{-7}H^2_d$. For simplification, 9.8062, the mean value of g at lat. 45° and sea-level is substituted for g_ϕ in the second term and then approximately,

$$h = (10/g_\phi)H_d + 1.637 \times 10^{-7}\,H^2_d \tag{5}$$

Table 699 is computed from (5) and values of g obtained as before.

References: Dynamical Meteorology and Hydrography, V. Bjerkness and collaborators, Carnegie Institution, 1910; Avant-propos of the C. R. des Jours internationaux 1923, Commission internationale de la haute atmosphere, 1927, Secretary of the commission, c/o Royal Meteorological Society, London.

TABLE 699.—Equivalents, in Geodynamic Kilometers, of Geometric Heights in Kilometers for Various Latitudes

Geometric hts. in km	Latitude (degrees) Geodynamic heights									
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
30	29.202	29.207	29.220	29.241	29.266	29.293	29.318	29.339	29.353	29.358
25	24.354	24.358	24.370	24.387	24.408	24.430	24.451	24.469	24.480	24.484
20	19.499	19.502	19.511	19.525	19.542	19.560	19.576	19.590	19.600	19.603
15	14.636	14.638	14.645	14.655	14.668	14.681	14.694	14.704	14.711	14.713
10	9.765	9.767	9.771	9.778	9.786	9.795	9.804	9.811	9.815	9.817
5	4.886	4.887	4.889	4.892	4.897	4.901	4.906	4.909	4.911	4.912
0	0	0	0	0	0	0	0	0	0	0

TABLE 700.—Equivalents, in Geometric Kilometers, of Dynamic Heights in Geodynamic Kilometers for Various Latitudes

Dynamic hts. Geodynamic km	Latitude (degrees) Geometric heights									
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
30	30.820	30.815	30.801	30.780	30.754	30.726	30.699	30.677	30.663	30.658
25	25.663	25.659	25.647	25.629	25.608	25.584	25.562	25.544	25.532	25.528
20	20.515	20.512	20.503	20.488	20.470	20.452	20.434	20.420	20.411	20.407
15	15.373	15.371	15.364	15.354	15.340	15.325	15.313	15.302	15.295	15.293
10	10.241	10.239	10.234	10.227	10.218	10.209	10.200	10.193	10.189	10.187
5	5.116	5.115	5.113	5.109	5.105	5.101	5.096	5.092	5.090	5.089
0	0	0	0	0	0	0	0	0	0	0

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TABLE 701.—Temperature Variation of Lower 25 Km with Latitude and Altitude, Northern Hemisphere (Ramanathan)

From figure adapted from Nature (Ramanathan, 123, 834, 1929) by Samuels (Monthly Weath. Rev., 57, 382, 1929). *gkm*, at right of figure indicates geodynamic kilometers (see Tables 698-700 for geodynamic kilometers). The tropopause is the boundary between the lower stratosphere and the upper troposphere. There have been incorporated by Samuels as indicated at the bottom of the plot certain values observed at aerological stations in the United States. The agreement is good. The differences are probably due to greater extremes found in continental America. The broken lines are based on few observations and are mainly conjectural. It is to be noted that:

(1) The stratosphere is not isothermal over any particular place; above a certain level there is a tendency for the temperature to increase with height. (2) The coldest air over the earth, about 185° K.,* lies at the height of some 17 *gkm* over the equator, a flat ring surrounded by rings of warmer air. (3) The tropopause surface has a relatively steep slope toward the pole between latitudes 30° and 50° in summer, 25° and 45° in winter. (4) The ring of lowest temperature is displaced towards the summer hemisphere. (5) There is a ridge of high temperature in the tropopause between latitudes 20° and 40° N. in summer corresponding to the ridge of high pressure at 8 km over these latitudes.

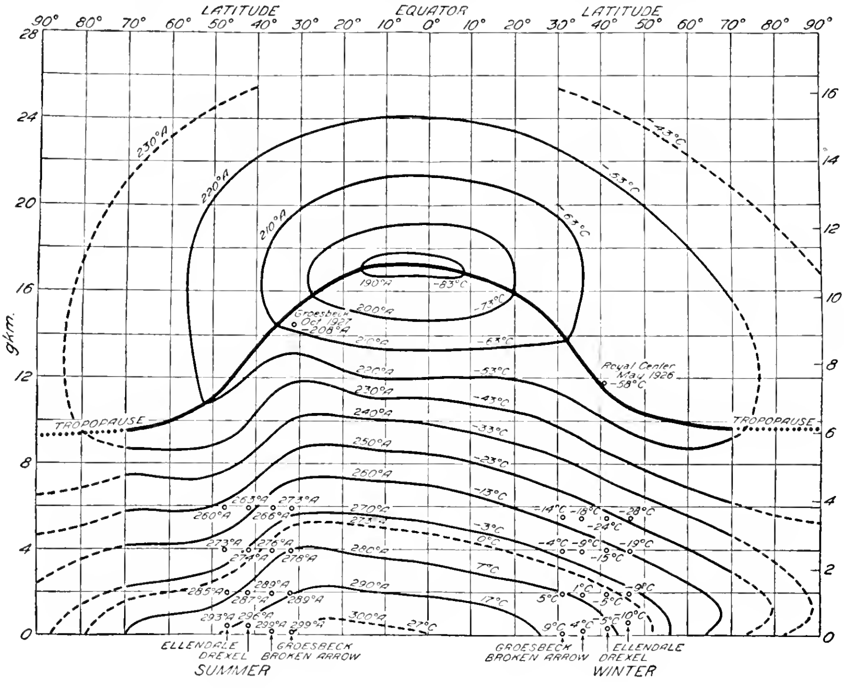


TABLE 702.—Seasonal Variation of Tropopause at Agra and Batavia

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Batavia °K.	184	185	186	187	188	192	193	194	193	190	187	184
Agra	203	203	203	203	200	195	193	193	193	194	200	204

TABLE 703.—Seasonal Variation Height of Tropopause over Batavia (km)

(Bemmelen, Proc. Roy. Acad. Amsterdam, 20., 1313.)

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
17.8	17.6	17.3	17.0	16.5	16.2	16.0	16.5	17.0	17.4	17.6	17.7

* In the Figure, °A is used equivalent to °K.

THE EARTH'S ATMOSPHERE

TABLE 704.—Atmospheric Ozone

This table shows the variation of atmospheric ozone (layer about 40 to 50 km above the earth's surface), with latitude and time of the year, from measures in long-wave portions of Hartley ultra-violet band 0.230 to 0.310 μ, by Doctor Dobson and his associates (Proc. Roy. Soc. 110A, 660, 1926 and 122A, 456, 1929); prepared partly from unpublished data. Measures are in cm of ozone at n. t. p. As only one year's observations are available for most stations these figures must be regarded as approximate.

Latitude	Jan.	Mar.	May	July	Sept.	Nov.
60°N.	0.305	*0.350*	0.330	0.285	*0.250*	0.255
40 N.	.260	*.280*	.270	.250	.225	*.220*
20 N.	.205	.220	*.225*	.220	.205	*.200*
0	*.190*	.195	.200	*.205*	.205	.200
20 S.	.210	*.205*	.210	.215	*.220*	.220
40 S.	.240	*.230*	.250	.290	*.310*	.280

Values are very steady from day to day in equatorial regions; in temperate latitudes large variations occur (up to 0.1 cm) which are apparently associated with meteorological conditions (Dobson).

TABLE 705.—Mean Free Path, Air Molecules

(Mavis, Terr. Mag., 1928–29.)

Values of mean free path, λ, of air molecules, at different heights, for the density conditions of Table 697, col. 9.

Z	Summer		Winter	
	Day	Night	Day	Night
km				
0	6.32×10^{-6}	6.32×10^{-6}	6.04×10^{-6}	6.04×10^{-6}
20	8.52×10^{-5}	8.48×10^{-5}	8.75×10^{-5}	1.09×10^{-4}
40	1.50×10^{-3}	1.72×10^{-3}	1.88×10^{-3}	2.48×10^{-3}
60	1.63×10^{-2}	3.19×10^{-2}	2.90×10^{-2}	5.02×10^{-2}
80	1.57×10^{-1}	5.76×10^{-1}	4.36×10^{-1}	9.41×10^{-1}
100	1.04	1.02×10^{1}	6.24	1.95
120	6.29	1.51×10^{2}	8.70	3.81×10^{2}
140	3.66×10^{1}	2.56×10^{3}	1.15×10^{3}	7.10×10^{3}
160	2.11×10^{2}	4.21×10^{4}	1.47×10^{4}	1.21×10^{5}
180	1.20×10^{3}	6.47×10^{5}	1.83×10^{5}	2.22×10^{6}
200	6.52×10^{3}	9.09×10^{6}	2.17×10^{6}	2.65×10^{7}
300	2.10×10^{7}	1.67×10^{9}	1.03×10^{9}	2.06×10^{9}
400	1.29×10^{9}	....	....	....

Table 706

ACCELERATION OF GRAVITY

For Sea-Level and Different Altitudes

Calculated from U. S. Coast and Geodetic Survey formula, p. 134 of Special Publication No. 40 of that Bureau.

$$g = 9.78039\ (1 + 0.005294 \sin^2 \phi - 0.000007 \sin^2 2\phi)\ \mathrm{m}$$
$$g = 32.08783\ (1 + 0.005294 \sin^2 \phi - 0.000007 \sin^2 2\phi)\ \mathrm{ft.}$$

Latitude ϕ	g cm/sec²	log g	g ft./sec²	Latitude ϕ	g cm/sec²	log g	g ft./sec²
0°	978.039	2.9903562	32.0878	50°	981.071	2.9917004	32.1873
5	.078	.9903735	.0891	51	.159	.9917394	.1902
10	.195	.9904254	.0929	52	.247	.9917784	.1931
12	.262	.9904552	.0951	53	.336	.9918177	1960
14	.340	.9904898	.0977	54	.422	.9918558	.1988
15	978.384	2.9905094	32.0991	55	981.507	2.9918934	32.2016
16	.430	.9905298	.1007	56	.592	.9919310	2044
17	.480	.9905520	.1023	57	.675	.9919677	.2071
18	532	.9905750	.1040	58	.757	.9920040	2098
19	.585	.9905985	.1057	59	.839	.9920403	.2125
20	978.641	2.9906234	32.1076	60	981.918	2.9920752	32.2151
21	.701	.9906500	.1095	61	.995	.9921073	.2176
22	763	.9906775	.1116	62	982.070	.9921424	.2201
23	.825	.9907050	.1136	63	.145	.9921756	.2225
24	.892	.9907348	.1158	64	.218	.9922079	.2249
25	978.960	2.9907649	32.1180	65	982.288	2.9922388	32.2272
26	979.030	.9907960	.1203	66	.356	.9922689	.2295
27	.101	.9908275	.1227	67	.422	.9922981	.2316
28	.175	9908603	.1251	68	.487	.9923268	.2338
29	..251	.9908940	.1276	69	.549	.9923542	.2358
30	979.329	2.9909286	32.1302	70	982.608	2.9923803	32.2377
31	.407	.9909632	.1327	71	.665	.9924055	.2396
32	.487	.9909987	.1353	72	.720	.9924298	.2414
33	.569	.9910350	.1380	73	.772	.9924528	.2431
34	.652	.9910718	.1407	74	.822	.9924749	.2448
35	979.737	2.9911095	32.1435	75	982.868	2.9924952	32.2463
36	.822	.9911472	.1463	76	.912	.9925147	.2477
37	.908	.9911853	.1491	77	.954	.9925332	.2491
38	.995	.9912238	.1520	78	.992	.9925500	.2503
39	980.083	.9912628	.1549	79	983.027	.9925655	.2515
40	980.171	2.9913018	32.1578	80	983.059	2.9925796	32.2525
41	.261	.9913417	.1607	81	.089	.9925929	.2535
42	.350	.9913812	.1636	82	.115	.9926043	.2544
43	.440	.9914210	.1666	83	.139	.9926149	.2552
44	.531	.9914613	.1696	84	.160	.9926242	.2558
45	980.621	2.9915011	32.1725	85	983.178	2.9926321	32.2564
46	.711	.9915410	.1755	86	.191	.9926379	.2569
47	.802	.9915814	.1785	87	.203	.9926432	.2572
48	.892	.9916212	.1814	88	.211	.9926467	.2575
49	.981	.9916606	.1844	90	983.217	.9926494	.2577

To reduce log g (cm. per sec. per sec.) to log g (ft. per sec. per sec.) add log 0.03280833 = 8.5159842 − 10.

The standard value of gravity, used in barometer reductions, etc., is 980.665. It was adopted by the International Committee on Weights and Measures in 1901. It corresponds nearly to latitude 45° and sea-level.

Free-air Correction for Altitude

−0.0003086 cm/sec²/m when altitude is in meters.
−0.000003086 ft/sec²/ft when altitude is in feet.

Altitude.	Correction.	Altitude.	Correction.
200 m.	−0.0617 cm/sec²	200 ft.	−0.000617 ft./sec²
300	.0926	300	.000926
400	.1234	400	.001234
500	.1543	500	.001543
600	.1852	600	.001852
700	.2160	700	.002160
800	.2469	800	.002469
900	.2777	900	.002777

Table 707

ACCELERATION OF GRAVITY, VARIOUS WORLD STATIONS

The following more recent gravity determinations (Potsdam System) serve to show the accuracy which may be assumed for the values in Table 706, except for the three stations in the Arctic Ocean. The error in the observed gravity is probably not greater than 0.010 cm/sec², as the observations were made with the half-second invariable pendulum, using modern methods.

In recent years the Coast and Geodetic Survey has corrected the computed value of gravity for the effect of material above sea-level, the deficiency of matter in the oceans, the deficiency of density in the material below sea-level under the continents and the excess of density in the earth's crust under the ocean, in addition to the reduction for elevation. Such corrections make the computed values agree more closely with those observed. See special publication No. 40 of the U. S. Coast and Geodetic Survey entitled, "Investigations of Gravity and Isostasy," by William Bowie, 1917; also Special Publication No. 10 of same bureau entitled, "Effect of Topography and Isostatic Compensation upon the Intensity of Gravity," by J. F. Hayford and William Bowie, 1912.

Name.	Latitude.	Elevation, meters.	Gravity, cm/sec²		Reference.
			Observed.	Reduced to sea-level.	
Kodaikanal, India	10° 14'	2336	977.645	978.366	1
Ootacamund, India	11 25	2254	977.735	978.427	2
Madras, India	13 4	6	978.279	978.281	2
Jamestown, St. Helena	−15 55	10	978.712	978.715	2
Cuttack, India	20 29	28	978.659	978.668	2
Amraoti, India	20 56	342	978.609	978.714	2
Jubbulpur, India	23 9	447	978.719	978.856	2
Gaya, India	24 48	110	978.884	978.918	2
Siliguri, India	26 42	118	978.887	978.923	2
Kuhrja, India	28 14	198	979.082	979.143	2
Galveston, Texas	29 18	3	979.272	979.273	2
Rajpur, India	30 24	1012	979.002	979.313	2
Alexandria, La.	31 19	24	979.429	979.436	2
St. Georges, Bermuda	32 21	2	979.806	979.807	2
McCormick, S. C.	33 55	163	979.624	979.674	2
Shamrock, Texas	35 13	708	979.577	979.795	2
Cloudland, Tenn.	36 6	1890	979.383	979.966	2
Mount Hamilton, Cal.	37 20	1282	979.660	980.056	2
Kala-i-Chumb, Turkestan	38 27	1345	979.462	979.877	2
Denver, Col.	39 41	1638	979.609	980.114	2
Hachinohe, Japan	40 31	21	980.359	980.365	2
Chicago, Ill.	41 47	182	980.278	980.334	2
Albany, N. Y.	42 39	61	980.344	980.363	2
Florence, Italy	43 45	184	980.401	980.548	2
Minneapolis, Minn.	44 59	256	980.597	980.676	2
Simplon Hospice, Switzerland	46 15	1998	980.202	980.819	2
Fort Kent, Me.	47 15	160	980.765	980.814	2
Sandpoint, Idaho	48 16	637	980.680	980.877	2
Medicine Hat, Canada	50 2	664	980.865	981.070	2
Field, Canada	51 24	1239	980.745	981.127	2
Magleby, Denmark	54 47	14	981.502	981.506	1
Copenhagen, Denmark	55 41	14	981.559	981.563	1
St. Paul Island, Alaska	57 7	10	981.726	981.729	2
Fredericksvarn, Norway	59 0	10	981.874	981.877	1
Christiania, Norway	59 55	28	981.927	981.936	1
Ashe Inlet, Hudson Strait	62 33	15	982.105	982.110	3
St. Michael, Alaska	63 28	1	982.192	982.192	2
Hatnarfjordr, Iceland	64 3	4	982.266	982.267	1
Niantilik, Cumberland Sound	64 54	7	982.273	982.275	3
Glaesibaer, Iceland	65 46	10	982.342	982.345	1
Sorvagen, Norway	67 54	19	982.622	982.628	2
Umanak, Greenland	70 40	10	982.590	982.593	3
Danes Island, Spitzbergen	79 46	3	983.078	983.079	1
Arctic Sea	84 12	0	983.109	983.109	1
Arctic Sea	84 52	0	983.174	983.174	1
Arctic Sea	85 55	0	983.155	983.155	1

References: (1) Report 16th General Conference International Geodetic Association, London and Cambridge, 1909, 3d Vol. by Dr. E. Borrâss, 1911; (2) U. S. Coast and Geodetic Survey, Special Publ. No. 40; * (3) U. S. Coast and Geodetic Survey, Report for 1897, Appendix 6.*

* For references (2) and (3), values were derived from comparative experiments with invariable pendulums, the value for Washington being taken as 980.112. For the latter, Appendix 5 of the Coast and Geodetic Survey Report for 1901, and pages 25 and 244 of the 3d vol. by Dr. E. Borrâss in 1911 of the Report of the 16th General Conference of the Intern. Geodetic Association, London and Cambridge, 1909. As a result of the adjustment of the net of gravity base stations throughout the world by the Central Bureau of the Intern. Geodetic Association, the value of the Washington base station was changed to 980.112.

Table 708

ACCELERATION OF GRAVITY (g) IN THE UNITED STATES

The following table is abridged from one for 219 stations given on pp. 50 to 52, Special Publication No. 40, **U. S.** Coast and Geodetic Survey. The observed values depend on relative determinations and on adopted value of 980.112 for Washington (Coast and Geodetic Survey Office, see footnote, Table 707). There are also given terms necessary in reducing the theoretical value (Table 565) to the proper elevation (free-air) and to allow for topography and isostatic compensation by the Hayford method (see introductory note to Table 707).

To a certain extent, the greater the bulk of material below any station, the less its average density. This phenomenon is known as isostatic compensation. The depth below sea-level to which this compensation extends is about 96 km. Below this depth any mass element is subject to equal (fluid) pressure from all directions.

Station.	Latitude.	Longitude.	Elevation, meters.	Observed g cm/sec²	Correction. Elevation, cm/sec²	Correction. Topography and compensation, cm/sec²
Key West, Fla.	24° 33.6′	81° 48.4′	1	978.970	0.000	+0.035
New Orleans, La.	29 57.0	90 4.2	2	979.324	−.001	+.013
Austin, Tex. university	30 17.2	97 44.2	189	979.283	−.058	−.001
El Paso, Tex.	31 46.3	106 29.0	1146	979.124	−.354	+.001
Yuma, Ariz.	32 43.3	114 37.0	54	979.529	−.017	−.010
Charleston, S. C.	32 47.2	79 56.0	6	979.546	−.002	+.016
Birmingham, Ala.	33 30.8	86 48.8	179	979.536	−.055	+.011
Arkansas City, Ark.	33 36.5	91 12.2	44	979.600	−.014	+.005
Atlanta, Ga. capitol.	33 45.0	84 23.3	324	979.524	−.100	+.014
Beaufort, N. C.	34 43.1	76 39.8	1	979.729	−.000	+.036
Little Rock, Ark.	34 45.0	92 16.4	89	979.721	−.027	+.001
Memphis, Tenn.	35 8.8	90 3.3	80	979.740	−.025	+.002
Charlotte, N. C.	35 13.8	80 50.8	228	979.727	−.070	+.015
Las Vegas, N. Mex.	35 35.8	105 12.1	1960	979.204	−.605	+.017
Knoxville, Tenn.	35 57.7	83 55.	280	979.712	−.086	−.001
Grand Canyon, Ariz.	36 5.3	112 6.8	849	979.463	−.262	−.096
Cloudland, Tenn.	36 6.2	82 7.9	1890	979.383	−.583	+.130
Mount Hamilton, Cal., Obs'y	37 20.4	121 38.6	1282	979.660	−.396	+.120
Richmond, Va.	37 32.2	77 26.1	30	979.960	−.009	+.010
San Francisco, Cal.	37 47.5	122 25.7	114	979.965	−.035	+.045
St. Louis, Mo., university	38 38.0	90 12.2	154	980.001	−.048	+.001
Pike's Peak, Col.	38 50.3	105 2.0	4293	978.954	−1.325	+.187
Colorado Springs, Col.	38 50.7	104 49.0	1841	979.490	−.568	−.007
Washington, D. C., Bur. St'ds.	38 56.3	77 4.0	103	980.095	−.032	+.012
Wallace, Kans.	38 54.7	101 35.4	1005	979.755	−.310	.000
Green River, Utah	38 59.4	110 9.9	1243	979.636	−.384	−.043
Cincinnati, Ohio, obs'y	39 8.3	84 25.3	245	980.004	−.076	+.002
Baltimore, Md., university	39 17.8	76 37.3	30	980.097	−.009	+.006
Terre Haute, Ind.	39 28.7	87 23.8	151	980.072	−.047	+.001
Denver, Col., university obs'y.	39 40.6	104 56.9	1638	979.609	−.505	−.015
Philadelphia, Pa., university	39 57.1	75 11.7	16	980.196	−.005	+.009
Wheeling, W. Va.	40 4.0	80 43.4	205	980.085	−.063	−.003
Princeton, N. J.	40 21.0	74 39.5	64	980.178	−.020	+.013
Pittsburg, Pa.	40 27.4	80 0.6	235	980.118	−.073	.000
Salt Lake City, Utah	40 46.1	111 53.8	1322	979.803	−.408	−.041
New York, N. Y., university	40 48.5	73 57.7	38	980.267	−.012	+.011
Winnemucca, Nev.	40 58.4	117 43.8	1311	979.844	−.404	−.004
Cleveland, Ohio	41 30.4	81 36.6	210	980.241	−.065	.000
Chicago, Ill., university	41 47.4	87 36.1	182	980.278	−.056	+.007
Worcester, Mass.	42 16.5	71 48.5	170	980.324	−.052	+.018
Cambridge, Mass. observatory	42 22.8	71 7.8	14	980.398	−.004	+.010
Ithaca, N. Y., university	42 27.1	76 29.0	247	980.300	−.076	+.005
Fort Dodge, Iowa	42 30.8	94 11.4	340	980.311	−.105	+.002
Grand Rapids, Mich.	42 58.0	85 40.8	236	980.372	−.073	+.003
Madison, Wis., university	43 4.6	89 24.0	270	980.365	−.083	+.003
Boise, Idaho	43 37.2	116 12.3	821	980.212	−.253	−.042
Mitchell, S. Dak. university	43 41.8	98 1.8	408	980.375	−.126	−.006
Lancaster, N. H.	44 29.5	71 34.3	261	980.486	−.081	+.007
Grand Canyon, Wyo.	44 43.3	110 29.7	2386	979.899	−.736	+.038
Minneapolis, Minn.	44 58.7	93 13.9	256	980.597	−.079	−.005
Calais, Me.	45 11.2	67 16.9	38	980.631	−.012	+.010
Miles City, Mont.	46 24.2	105 50.	718	980.539	−.222	−.020
Seattle, Wash. university	47 39.6	122 18.3	58	980.733	−.018	−.020
Pembina, N. Dak.	48 58.1	97 14.9	243	980.917	−.075	−.009

Table 709

SOME PLACES OF ANOMALOUS GRAVITY

With their longitudes, latitudes, and heights above sea-level

(See Borrass, Verh. 16 allgem. Konferenz der Intern. Erdmessung, Berlin, 1911, 1914. The departures are from the values of gravity normally expected from Table 706.)

Longitude east of Greenwich		Latitude		Altitude above sea-level m	Gravity cm/sec.²	Departure from value of table	Place
°	′	°	′				
14	59.9	37	44.3	2943	979.350	+287	Etna
− 5	43.8	−15	55.4	10	978.682	+260	St. Helena
−157	51.8	21	18.1	4	978.960	+243	Honolulu
0	8	42	55.8	2877	979.779	+233	Pic du Midi
− 16	14.4	28	28.1	11	979.431	+223	Santa Cruz
6	52	45	50	4807	979.401	+188	Mont Blanc
77	27.9	10	13.8	2346	977.645	+164	Kodaikanal
− 61	4.5	14	36.0	4	978.520	+155	Fort de France
− 25	20.6	37	44.2	19	980.118	+152	Ponta Delgada
10	37	51	48.0	1140	981.015	+136	
15	4.7	37	30.2	43	980.065	+127	Catania
13	56.6	40	44.5	35	980.348	+122	Ischia
15	44.6	50	44.2	1604	980.761	+119	Schneekoppe
− 75	50.8	20	.8	4	978.756	+115	Santiago de Cuba
− 78	50.0	− 0	14.0	2825	977.281	+114	Quito
141	19	40	16	104	980.270	+107	Fukuoka
−121	38.7	37	20.4	1282	979.648	+106	Lick Observatory
140	52	38	15	33	980.109	+103	
15	33.4	38	11.5	5	980.111	+102	Messina
10	23	63	25.9	37	982.114	− 53	
6	52	45	55	1050	980.323	− 57	
35	11.5	47	48.5	49	980.802	− 58	
9	11.5	45	28.0	176	980.562	− 58	Milan-Brera
69	17.7	41	19.5	478	980.082	− 59	Tashkent
68	15.3	58	11.4	56	981.697	− 59	Tobolsk
78	3.2	30	19.5	683	979.065	− 77	Dehra-Dun
11	24.1	47	16.2	576	980.570	− 78	Innsbruck
48	18.5	42	3.1	−26	980.280	− 83	Derbent
115	15.4	−31	57.2	58	979.378	− 88	Perth
12	2.8	44	13.5	26	980.441	−102	Forli
77	54.0	29	52.3	264	979.131	−106	Roorkee
−122	20.1	47	36.6	74	980.726	−108	Seattle
11	21.3	44	29.8	51	980.450	−110	Bologna
88	44.2	26	31.3	82	978.924	−118	

TABLE 710.—Length of Seconds Pendulum at Sea-Level and for Different Latitudes

	Length in cm	Log.	Length in inches.	Log.		Length in cm	Log.	Length in inches.	Log.
0	99.0961	1.996056	39.0141	1.591222	50	99.4033	1.997401	39.1351	1.592566
5	.1000	.996074	.0157	.591239	55	.4475	.997594	.1525	.592760
10	.1119	.996126	.0204	.591292	60	.4891	.997776	.1689	.592941
15	.1310	.996210	.0279	.591375	65	.5266	.997939	.1836	.593104
20	.1571	.996324	.0382	.591490	70	.5590	.998081	.1964	.593246
25	99.1894	1.996465	39.0509	1.591631	75	99.5854	1.998196	39.2068	1.593361
30	.2268	.996629	.0656	.591794	80	.6047	.998280	.2144	.593446
35	.2681	.996810	.0819	.591976	85	.6168	.998332	.2191	.593498
40	.3121	.997002	.0992	.592168	90	.6207	.998350	.2207	.593515
45	.3577	.997201	.1171	.592367	—	—	—	—	—

Calculated from Table 706 by the formula $l = g/\pi^2$. For each 100 ft. of elevation subtract 0.000953 cm or 0.000375 in. or 0.0000313 ft. This table could also have been computed by either of the following formulae derived from the gravity formula at the top of Table 706.

$$l = 0.990961(1 + 0.005294 \sin^2\phi - 0.000007 \sin^2 2\phi) \text{ meters}$$
$$l = 0.990961 + 0.005246 \sin^2\phi - 0.000007 \sin^2 2\phi \text{ meters}$$
$$l = 39.014135(1 + 0.005294 \sin^2\phi - 0.000007 \sin^2 2\phi) \text{ inches}$$
$$l = 39.014135 + 0.206535 \sin^2\phi - 0.000276 \sin^2 2\phi \text{ inches}$$

TABLE 711.—Miscellaneous Geodetic Data

(Replaced by Table 716)

TABLE 712.—Miscellaneous Geographical Data (see page 650)

(The data on this page were compiled by R. W. Goranson, Geophysical Laboratory, Carnegie Institution, 1930.)

Land area, 148,847,000 km²; Ocean area, 361,254,000 km².

Mean elevation land above sea-level, 825 m.

Mean depth oceans, 3,680 m.

Highest known mountain, Mt. Everest, India, 87° E., 28° N., 8840 meters.

Greatest known sea-depths: Mindanao deep 10,430 meters, $<10°$ N., 127° E.; Puerto Rico deep 8,525 meters, 19°35′ N., 67°43′ W.

Thermal gradient: Not well-known; from Van Orstrand's data average is 30°C per km depth but may be very different; variations observed are from 9 (Johannesburg, S. Africa) to 54 (Queensland) degrees C per km depth. Max. depth measured, 2,286 m.

TABLE 713.—Densities and Pressures of Earth's Interior

Depth	Density	Pressure	Rock type
0 km	2.7 g/cm³		Granitic
10	2.7	0.0027×10^6 kg/cm²	
30	3.0	.0067	Basaltic
60	3.4	.0171	Peridotitic
120	3.5	.0381	
400	3.75	.131	
800	4.0	.30	
1200	4.25	.47	
1700	4.4	.68	
2000	5.8	.84	
2450	7.25	1.135	
2900	9.0	1.5	Transition layer
3200	9.6	1.7	
4800	10.25	2.8	Ni-Fe core
6370	10.7	3.1	

(Below 800 km, due to Adams, Williamson.)

TABLE 714.—Velocities of Earthquake Waves

V_p is the velocity in km/sec. of the primary or condensational wave, V_s, of the secondary or distortional wave. Turner speaks of them as the *push* and *shake* waves.

Layer:	V_p, km/sec.	V_s, km/sec.
0 to 20 ± 10 km depth, depending on locality	5.4 to 5.6, depending on locality. May reach 6.1	3.2 ± 0.3
20 ± 10 to 45 ± 10 km depth, depending on locality	6.25 to 6.75*, depending on locality	3.5 ± 0.3*
Between 45 ± 10 and 2900 km depth:		
45 ± 10	8.0 ± 0.1	4.4 ± 0.2
1300	12.5 ± .1	6.9 ± .2
2400	13.5 ± .1	7.5 ± .2
<2900	13.5 ± .1	7.4 ± .2
Core, 2700 to 6370 km (center):		
>2900	8.7 ± .2	?
6000	10.9 ± .2	?

* B. Gutenberg, H. Jeffreys, K. Suda, A. and S. Mohorovicic, V. Conrad.

TABLE 715.—Elastic Constants of Earth's Interior

Depth km	Bulk modulus $\times 10^{-12}$ dynes/cm²	Rigidity $\times 10^{-12}$ dynes/cm²	Depth km	Bulk modulus $\times 10^{-12}$ dynes/cm²	Rigidity $\times 10^{-12}$ dynes/cm²
0	0.415	0.26	1200	3.6 ± 0.3	2.2 ± 0.3
0–20	.5 ± 0.05	.3 ± 0.5	1700	4.2 ± .3	2.7 ± .3
20–45	.7 ± .1	.4 ± .1	2850	8 ± 2	4.0 ± 1.0
45–120	1.4 ± .2	.6 ± .1	2900	7 ± 1 ?	Smaller than at surface, perhaps zero.
120–400	1.6 ± .2	1.0 ± .2	6370	12 ± 10 ?	

MISCELLANEOUS GEOPHYSICAL DATA

Equatorial radius of earth, a, 6,378,388 m $\pm$ 18.
Ellipticity, flattening, $(a-b)/a$, 1/297 or 0.003,367,003,4.

(Adopted at International Geodetic and Geophysical Union, 1924.)

Polar radius, b, 6,356,911.946 m.
Square of the eccentricity, e^2, or $(a^2-b^2)/a^2$, 0.006,722,670,0.
Quadrant of equator, 10,019,148.4 m; ditto of meridian, 10,002,288.3 m.
Area of ellipsoid, 510,100,934 km^2; volume of ditto, 1,083,319,780,000 km^3.
Radius of sphere having same area, 6,371,227.7 m.
Radius of sphere having same volume, 6,371,221.3 m.

Difference between geographical latitude, Φ, and geocentric latitude: Φ'.

$$\Phi - \Phi' = 695''6635 \sin 2\Phi - 1''1731 \sin 4\Phi + 0''0026 \sin 6\Phi$$
$$= 695''6635 \sin 2\Phi' + 1''1731 \sin 4\Phi' + 0''0026 \sin 6\Phi'$$

Newtonian constant of gravitation, G, $(6.664 \pm 0.002) \times 10^{-8}$ dyne cm^{2}g^{-2} (Heyl).
Mean density of the earth, 5.522 (Lambert).
Continental surface density of the earth, 2.67. } (Harkness.)
Mean density outer 10 miles of crust, 2.40. } (Harkness.)
Rigidity, μ, 8.6×10^{11} c.g.s. units. } Michelson, Astrophys. Journ., 39, 105, 1914.
Viscosity, 10.9×10^{16} c.g.s. units (comparable to steel). } Michelson, Astrophys. Journ., 39, 105, 1914.

Moments of inertia of the earth, the principal moments being taken as A, B, and C, and C the greatest (De Sitter, 1924):

$A = B = 0.33235 \times Ea^2$ $\qquad C = 0.33344 \times Ea^2$ $\qquad C - A = 0.0010921 \times Ea^2$.
$(C - A)/C = 0.0032774$, from precession.
Mass of the earth $= E = 5.983 \times 10^{24}$ kg; $a =$ equatorial semidiameter.

Formulae for theoretical gravity at the surface of the ellipsoid (which is assumed to be an equipotential surface):

$$\gamma = \gamma_e\,(1 + 0.005288 \sin^2 \Phi - 0.000006 \sin^2 2\Phi) \text{ cm/sec}^2.$$
$$= \gamma_{45}\,(1 + 0.002637 \cos^2 \Phi + 0.000006 \cos^2 2\Phi) \text{ cm/sec}^2.$$

$\gamma_e =$ sea-level gravity at equator		$\gamma_{45} =$ sea-level gravity at lat. 45°	
$= 978.038$ cm/sec^2.	Bowie	$= 980.621$ cm/sec^2.	Bowie
.052	Helmert	.629	Helmert
.052	Heiskanen	.630	Heiskanen

There is a systematic difference between gravity determinations over land or over sea, the latter being greater; this leads Bowie to favor a value of $978.52 \pm .008$ for the value above.

This systematic difference has led to the formula:

$$g = 978.052 \{ 1 + 0.005288 \sin^2 \phi - 0.000006 \sin^2 2\phi + 0.000023 \cos^2 \phi \cos 2(\lambda + 5°) \},$$

where $\lambda =$ east longitude. This longitude term has appeared to be indicated by the results of several observers.—Clarke, 1878, Helmert, 1915, and Heiskanen, 1928. It could be taken as indicating that the earth had three unequal axes.

Mean linear velocity of the earth in its orbit, 29.77 km/sec.
Mean linear velocity of rotation of earth at equator, 0.465 km/sec.
Rotational energy lost by tidal friction, 1.1×10^{19} erg/sec. (Jeffreys).
Angular velocity of rotation, 72.921×10^{-6} radians/mean-solar-second.
Rotational energy, 2.160×10^{36} ergs/sec.

(See Lambert, Science, 63, 242, Mar. 5, 1926; Journ. Wash. Acad. Sci., 18, 571, 1928.)

TABLE 717.—Age of Earth, Moon, and Strata

(See The Earth, by Jeffreys, 1929.)

The age of the earth is probably from (1.3 to 3) $\times 10^9$ years (radioactive data). Its liquefaction was probably complete within 5000 years, solidification within 15,000 years from start. The age of the earth's crust may be taken as roughly 2000 million years.

AGES OF GEOLOGIC STRATA

Late Oligocene	37,000,000 yrs.	Late pre-Cambrian (?)	587,000,000 yrs.
" Cretaceous (?)	59,000,000 "	Upper pre-Cambrian	640,000,000 "
Permian-Carboniferous	204,000,000 "	Middle pre-Cambrian	987,000,000 to 1,087,000,000 yrs.
Permian to Devonian	239,000,000 to 374,000,000 yrs.	Lower pre-Cambrian	1,257,000,000 "

Note (Science 73 (Suppl.), 10, Mar. 13, 1931): An age of the earth of at least 2,000,000,000 years was adopted by a committee (Kovarik, Holmes, Knopf, Brown, Lane) appointed by the National Research Council; the age of the oldest rock, a uranite from Sinyaya Palo, Carelia, Russia, 1,852,000,000.

TABLE 718(a).—Geologic Age Determinations Based on the Lead Method

(Knopf, Nat. Res. Council Bull. 80, 1931.)

Geologic age.	Mineral.	Locality.	Age (Millions of years) Based on $T_U = 4.56 \times 10^9$ $T_{Th} = 1.28 \times 10^{10}$	Age (Millions of years) Based on $T_U = 4.56 \times 10^9$ $T_{Th} = 1.65 \times 10^{10}$
Paleozoic; Devonian or Carboniferous.	Thorite	Norway	224	310
Latest Cambrian	Kolm	Sweden	450	
Pre-Cambrian	Bröggerite	Norway	915	910
Pre-Cambrian	Cleveite	Norway	967	964
Pre-Cambrian	Cleveite	Norway	986	965
Pre-Cambrian	Uraninite	S. Dakota	1,465	1,462
Pre-Cambrian	Uraninite	Russia	1,852	1,852

TABLE 718(b).—The Age of the Earth

(Taken from Nat. Res. Council Bull. 80, 1931.)

Radioactive disintegration presents the only reliable measure. No trace of a beginning can yet be found. "The oldest rocks have everywhere been made from preexisting and therefore still older materials of which no other relics now survive. . . . . The earth is older than the oldest granitic intrusion. It is impossible with the data available to know whether the highest reliable lead ratio so far obtained (Keystone uraninite, Black Hills, S. Dak.) represents the oldest granitic rocks. Accepting a ratio of 0.216 as an index of its age this is 1460 million years old. Before the oldest granites were intruded into the crust at least one cycle of denudation and sedimentation occurred indicated by the rocks into which the granites were injected. To the 1460 we should add perhaps 140, giving as the age some 1600 million years, as indicated by above mean. An upper limit assuming all rock lead of radioactive origin is 1600 million. The estimate of the total life of the earth (Russell, Holmes, loc. cit. p. 8) is some 3000 million years.

Strata accumulated: Max. since beginning of Cambrian from America data—260,000 ft.; 111,000 of this deposited during Paleozoic time, 86 are Mesozoic, 61,000 during Cenozoic.

TABLE 719

GEOCHEMICAL DATA

Eighty-three chemical elements (86 including Po, Ac and UrX_2) are found on the earth. Besides the eight occurring uncombined as gases, 23 may be found native, Sb, As, Bi, C, Cu, Au, Ir, Fe, Pb?, Hg, Ni, Os, Pd, Pt, Rh, Ru, Se, Ag, S, Ta ?, Te, Sn ?, Zn ?. Combined the elements form about 1000 known mineral species. Rocks are in general aggregates of these species. Some few (e. g., quartzite, limestone, etc.) consist of one specie. We have some knowledge of the earth to a depth of 10 miles. This portion may be divided into three parts: the innermost of crystalline or plutonic rocks, the middle, of sedimentary or fragmentary rocks, the outer of clays, gravels, etc. 93% of it is solid matter, 7% liquid, and the atmosphere amounts by weight to 0.03% of it. Besides the 9 major constituents of igneous rock (see 7th col. of table) 3 are notable by their almost universal occurrence, TiO_2, P_2O_5, and MnO. Bo, Gl, and Sc are also widely distributed.

The density of the earth as a whole is 5.52 (Burgess); continental surface, 2.67 and outer 10 miles of crust, 2.40 (Harkness). Computed from average chemical composition: outer ten miles as a whole, 2.77; northern continents 2.73; southern, 2.76; Atlantic basin, 2.83; Pacific basin, 2.88.

Data of Geochemistry, Clarke, Bul. 616, U. S. Geological Survey, 1916; Washington, J. Franklin. Inst. 190, p. 757, 1920.

AVERAGE COMPOSITION OF KNOWN TERRESTRIAL MATTER.

Atomic number and element.	Average composition.			Igneous rocks.	Average composition of lithosphere.					
	Litho-sphere, 93%	Hydro-sphere, 7%	Average including atmosphere.		Compound.	Igneous rocks, 95%	Shale, 4%	Sand-stone, 0.75%	Lime-stone, 0.25%	Weighted average.
8 O	47.33	85.79	46.43	47.29	SiO_2	59.09	58.10	78.33	5.19	59.77
14 Si	27.74	—	27.77	28.02	Al_2O_3	15.35	15.40	4.77	0.81	14.89
13 Al	7.85	—	8.14	7.96	Fe_2O_3	3.08	4.02	1.07	.54	2.69
26 Fe	4.50	—	5.12	4.56	FeO	3.80	2.45	.30	—	3.39
20 Ca	3.47	0.05	3.63	3.47	MgO	3.49	2.44	1.16	7 89	3.74
12 Mg	2.24	0.14	2.09	2.29	CaO	5.08	3.11	5.50	42.57	4.86
11 Na	2.46	1.14	2.85	2.50	Na_2O	3.84	1.30	.45	.05	3.25
19 K	2.46	0.04	2.60	2.47	K_2O	3.13	3.24	1.31	.33	2.98
1 H	0.22	10.67	0.127	0.16	H_2O	1.14	5.00	1.63	.77	2.02
22 Ti	0.46	—	.629	.46	TiO_2	1.05	.65	.25	.06	.77
6 C	.19	0.002	.027	.13	ZrO_2	0.039	—	—	—	.02
17 Cl	.06	2.07	.055	.063	CO_2	.102	2.63	5.03	41.54	.70
35 Br	—	0.008	—	—	P_2O_5	.30	.17	.08	.04	.28
15 P	.12	—	130	.13	S	.053	—	—	.09	.10
16 S	.12	.09	.052	.103	SO_3	—	.64	.07	.05	.03
56 Ba	.08	—	.048	.092	Cl	.056	—	—	.02	.06
25 Mn	.08	—	.096	.078	F	.078	—	—	—	.09
38 Sr	.02	—	.018	.033	BaO	.055	.05	.05	—	.09
7 N	—	—	—	—	SrO	.022	—	—	—	.04
9 Fl	.10	—	.077	.10	MnO	.125	—	—	.05	.09
etc.	.50	—	.111	.091	NiO	.025	—	—	—	.025
					Cr_2O_3	.056	—	—	—	.05
					V_2O_3	.032	—	—	—	.025
					Li_2O	.007	—	—	—	..01
					C	—	.80	—	—	.03

AVERAGE COMPOSITION OF METEORITES: The following figures give in succession the element, atomic number (bracketed), and the percentage amount in stony meteorites (Merrill, Mem. Nat. Acad. Sc. 14, p. 28, 1916). The "iron" meteorites contain a much larger percentage of iron and nickel, but there is a tendency to believe that with such meteorites the composition is altered by the volatilization or burning up of the other material in passing through the air. Note the greater abundance of elements of even atomic number (97.2 per cent).

O (8)	36.53	Fe (26)	23.32	Si (14)	18.03	Mg (12)	13.60
S (16)	1.80	Ca (20)	1.72	Al (13)	1.53	Ni (28)	1.52
Na (11)	1.64	Cr (24)	0.32	Mn (25)	0.23	K (19)	0.17
C (6)	0.15	Co (27)	0.12	Ti (22)	0.11	P (15)	0.11
H (1)	0.09	Cu (29)	0.01	Cl (17)	0.09	V (23)	tr.
Ru (44)	tr.	Pd (46)	tr.	Pt (78)	tr.	Ir (77)	tr.

TABLE 720

THE EARTH'S ROTATION: ITS VARIATION

(Jeffreys, The Earth, Macmillan, 1929. Innes, Changes in the Length of the Day, Scientia, 42, 69, 1927; Brown, Nature, 119, 200, 1927; Journ. Roy. Astron. Soc. Canada, 24, 177, 1930.)

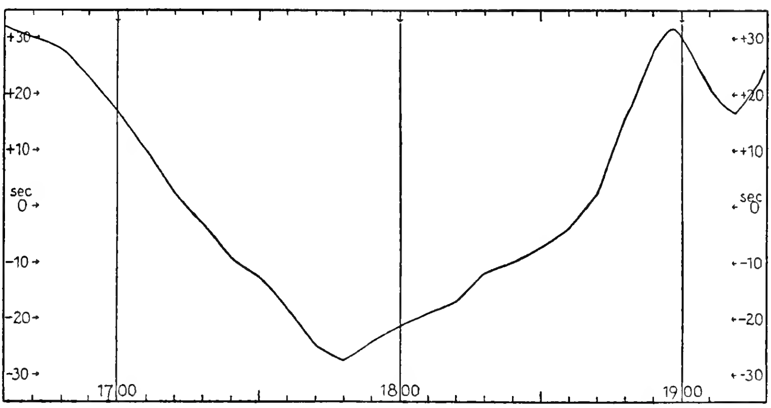
From eclipses, occultations, Fotheringham (M. N., 81, 104, 1920) deduces as the best value of the apparent solar acceleration 3.0″/(century)^2; lunar 21.6″/(century)^2. Lunar theory predicts 12.2″/(century)^2 leaving part attributable to tidal friction 9″/(century)^2.

Estimates of tidal friction losses (Jeffreys, Philos. Trans. A *221*, 239, 1920):

Irish Sea	0.6×10^{18} erg/sec.	So. China Sea	$— \times 10^{18}$ erg/sec.	Hudson Str.	0.2×10^{18} erg/sec.
Eng. Channel	1.1 " "	Okhotsk "	0.4 " "	" Bay	— " "
North Sea	1.7 " "	Bering "	15.0 " "	Fox Strait	1.4 " "
Yellow Sea	1.1 " "	Mallacca Str.	1.1 " "	Bay Fundy	0.4 " "

Other contributions are small. Total for spring tides 22×10^{18} erg/sec. 1.1×10^{19} erg/sec. average, corresponding to about 7″ secular acceleration per century per century. If Ω is earth's angular velocity of rotation, $d\Omega/dt = -2.5 \times 10^{-22}/\mathrm{sec}^2$. $\Omega = 7.3 \times 10^{-5}/\mathrm{sec}$. Ω changes by 10^{-5} of its amount in 3×10^{12} sec. or 10^5 years. The day *should* have lengthened by 1 sec. in 120,000 years.

The fluctuations in the earth's rate of rotation indicated by astronomical evidence are of a quite greater order of magnitude. Moreover the changes vary in sign whereas frictional effects should not. The observations come from deviations of the sun and moon from their gravitational orbits, the transits of Mercury, and eclipses of Jupiter's satellites. Changes in the speed of rotation of the earth rotation seem the only explanation. This may be due to shifts of matter within or on the earth. The following figure by Brown indicates that in 1928 the earth was about 25 sec. ahead of its average rotational motion during the last three centuries. The greatest apparent change is the loss or gain of one sec. in a whole year. (1 part in 30,000,000.)



IRREGULARITIES IN THE EARTH'S ROTATION DERIVED FROM THE MOON'S MOTION.

Tidal friction should make the earth rotate more slowly and the moon recede from the earth. The rate of dissipation of energy by friction is about 1.4×10^{19} erg/sec. The earth's rotation from this cause should have slowed by 4 hours during geologic time. The moon should continue to recede until its period of revolution and that of the earth's rotation are equal to 47 of our present days. The moon should then gradually approach the earth, ultimately coming within Roche's limit (about twice the earth's radius) breaking up possibly into a ring like Saturn's.

TABLE 721.—Tides, Sea-Level, Level Net

(Nat. Res. Council Bull. 78, 1931.)

Spring tides: When moon (new or full) is in line with sun (large).
Neap tide: When moon is in quadrature with sun (small).
Generally two high and two low each day. Variation in heights of two high and two low = "diurnal inequality."
River type tide, steep short period graph for flood, more inclined and longer for ebb. Extreme case = "bore," tide rises so rapidly it assumes form of wall several feet high. Most famous bores, Tsientang Kiang, China; Turnagain Arm, Alaska; Severn and the Wye, England; Seine in France; Hoogly, India; Petitcodiac, Canada.
Mean sea-level (geodetic): The equipotential surface which the oceans would assume if undisturbed by the tides and effects of wind and weather. Starting with mean sea-level at any given initial point the geodesist can determine by precise spirit leveling, the equipotential surface.
Mean sea-level (geographic): Determined by averaging actual tidal heights over a sufficient period. It is a local or geographic value. It is much disturbed by prevalent winds and local contours. Note difference between average of hourly readings (mean sea-level) and half-tide point (because of the shape of the tide height as related to time). On Atlantic coast $\frac{1}{2}$ tide level lies below mean by about 1/10 ft.; on Pacific above by 1/20 ft. Mean tide near rivers varies with rainfall. Nineteen years' observation used for full tide cycle. A fundamental level net has been connected with mean sea-level at Portland, Me., via Boston, Mass., Ft. Hamilton, N. Y., Sandy Hook and Atlantic City, N. J., Old Point Comfort and Norfolk, Va., Brunswick, Ga., Fernandina, St. Augustine, and Cedar Keys, Fla., Biloxi, Miss., Galveston, Tex., San Diego, San Pedro, San Francisco, Calif., Ft. Stevens, Oreg., and Seattle, Wash. The accuracy of high precision leveling is measured by the correction necessary to close circuits, about 0.00063 foot/mile. Mean sea-level differences:

Portland 16.94 cm higher than Ft. Hamilton.
Vancouver 10.28 cm higher than Seattle.
Galveston 24 cm higher than St. Augustine.
San Diego 40 cm higher than Galveston.
Fort Stevens 79 cm higher than San Diego.

Isthmus Panama, Pacific coast 20 cm higher than Atlantic.
Death Valley is 276 ft. (84.1 m) below sea-level, Mount Whitney 14,496 ft. (4418.4 m) above.

TABLE 722.—Magnetic and Electric Data for Sun and Earth

(Chapman, Cosmical magnetic phenomena, Nature, 124, 19, 1929.)

Sun's magnetic field too small to be measured by direct effects on earth; measured by Zeeman effect on spectrum lines.
Earth's magnetic axis inclined 12° to rotation axis.
Sun's magnetic axis inclined 4° to rotation axis.
Polarity of both same relation to direction of rotation.
Earth's field rotates at same speed as nearly rigid earth.
Sun's field and magnetic axis rotate more slowly than solar surface (31, 26 days, respectively).
Earth: Polar intensity of field $\frac{2}{3}$ gauss.
Sun: Estimated 50 gauss in reversing layer. Intense local fields frequent, 3000 gauss. The magnetic field of spots reverses each cycle (Proc. Astron. Soc. Pacific, 41, 136, 1929). The polarity of leading spot in a bipolar group in N. hemisphere is opposite that in the S. hemisphere—relationship reverses each new sun-spot cycle ∴ complete magnetic cycle is double sun-spot cycle.

Specific resistances:	Earth		Sun	(Chapman loc. cit.)
	Heaviside layer,	10^{10}	Reversing layer,	3×10^{10}
	Dry earth,	10^{15} to 10^{16}	Photosphere,	10^8, T, 10000° K.
	Sea water,	2×10^{10}	Center,	3×10^3, T, 4×10^7
	200-600 m deep,	3×10^{12}		

Drift currents in sun, + ions easterly.
Further characteristics of spots: (Milne, M. N. 90, 487, 1930; Russell.) Umbra (dark center), 800 (very small) to 80,000 km across: penumbra may reach 240,000 km. Generally short-lived. A few last several (3) rotations, very rarely 6; one in 1840, 18 months. Most occur in 2 belts 5° to 40° N. and S. latitudes, often occur in pairs (see above). Umbra temperature 4000° K. Evershed gives velocity of outburst from spot 2 km/sec.

TERRESTRIAL MAGNETISM

TABLE 723.—Magnetic Constants of the Earth

(Prepared by J. A. Fleming, Department of Terrestrial Magnetism, Carnegie Institution of Washington.)

If V be the magnetic potential of the earth, then

$$V/R = \Sigma c_m^n P_m^n \sin\phi \cos(m\lambda + a_m^n)$$

where R = earth's mean radius (6.37×10^8 cm), ϕ = latitude, λ = east longitude, n varies from 1 to ∞, and m from 0 to n. The field-components of total intensity F designated, X positive towards geographic north, Y positive towards geographic east, and Z positive towards nadir, are

$$X = -(1/R)\left(\frac{\partial V}{\partial\phi}\right) = -\Sigma c_m^n (\partial P_m^n/\partial\phi) \cos(m\lambda + a_m^n)$$

$$Y = -(1/R\cos\phi)(\partial V/\partial\lambda) = (1/\cos\phi)\Sigma m c_m^n P_m^n \sin(m\lambda + a_m^n)$$

$$Z = -\Sigma(n+1) c_m^n P_m^n \cos(m\lambda + a_m^n)$$

L. A. Bauer (Terr. Mag., 28, 1-28, 1923) made an analysis based on the latest values of the magnetic elements, epoch 1922, between the parallels 60° N. and 60° S. He found the following for the uniform portion of the earth's X, Y, and Z magnetic systems:

Quantity	Epoch 1922, c.g.s. units. X	Y	Z
M/R^3	+.31626	......	+.30699
M_p/R^3	+.30992	......	+.30084
M_e/R^3	+.06303	.06235	+.06113

where M is the earth's moment, and M_p and M_e are its axial and equatorial components.

For the same date Bauer deduced the following values in magnetic units:

$M = 8.04 \times 10^{25}$ c.g.s. $M_p = 7.88 \times 10^{25}$ c.g.s. $M_e = 1.60 \times 10^{25}$ c.g.s.

The magnetic field of the earth approximates that of a uniformly magnetized sphere, its magnetic axis inclined to that of geographical rotation. The equivalent axis intercepts the northern hemisphere in latitude 78° 32′ N. and longitude 69° 08′ W.

The intensity of the earth's magnetic field above the surface may be expressed as a first approximation (according to Schmidt) by $F(1 - 3h/R)$ where h is the elevation and R the earth's radius; that is, for each 2 km the field diminishes by approximately 0.1 per cent while the direction is practically unchanged.

If the earth's magnetism were distributed uniformly throughout its volume, the average intensity of magnetization would be 0.074 c.g.s. The equivalent intensity of magnetization has been steadily diminishing during the past 80 years at the average annual rate of about 1/1,500 part.

A. Nippoldt (Veröff. Preus. Meteor. Inst., Berlin, no. 372, 137-143, 1930) gives the following positions based on observations:

TABLE 724.—North Magnetic Pole

Year.	Latitude. ° ′	Longitude. ° ′	Source.
1831	70 05.4 N.	96 53.5 W.	Ross
1903	70 30 N.	95 30 W.	Amundsen

TABLE 725.—South Magnetic Pole

Year.	Latitude. ° ′	Longitude. ° ′	Source.
1841	75 05 S.	154 08 E.	Ross
1903	72 41 S.	156 25 E.	1st British Antarctic expedition
1909	72 25 S.	154 00 E.	2d British Antarctic expedition

The magnetic poles are not diametrically opposite, each being approximately 2300 kilometers (Gutenberg, Lehrb. Geophys., 400, 1929) from the antipodes of the other. These poles are defined as the points at which magnetic lines of force are normal to the earth's surface, and are to be distinguished from the extremities of the magnetic axis derived from analysis.

TERRESTRIAL MAGNETISM

TABLE 726.—World Isogonic Lines, Epoch 1930 (Lines of Equal Declination (*D*))

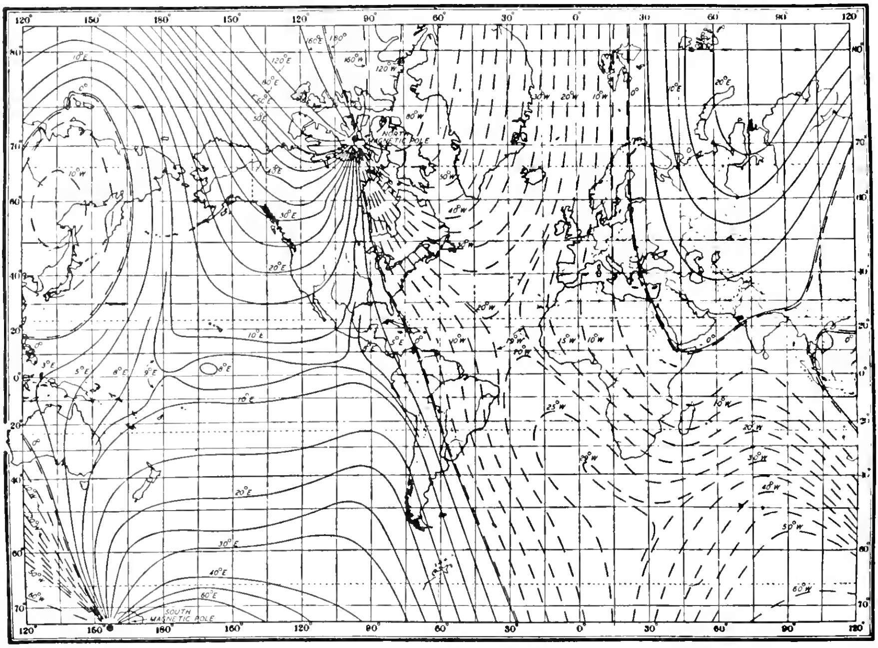
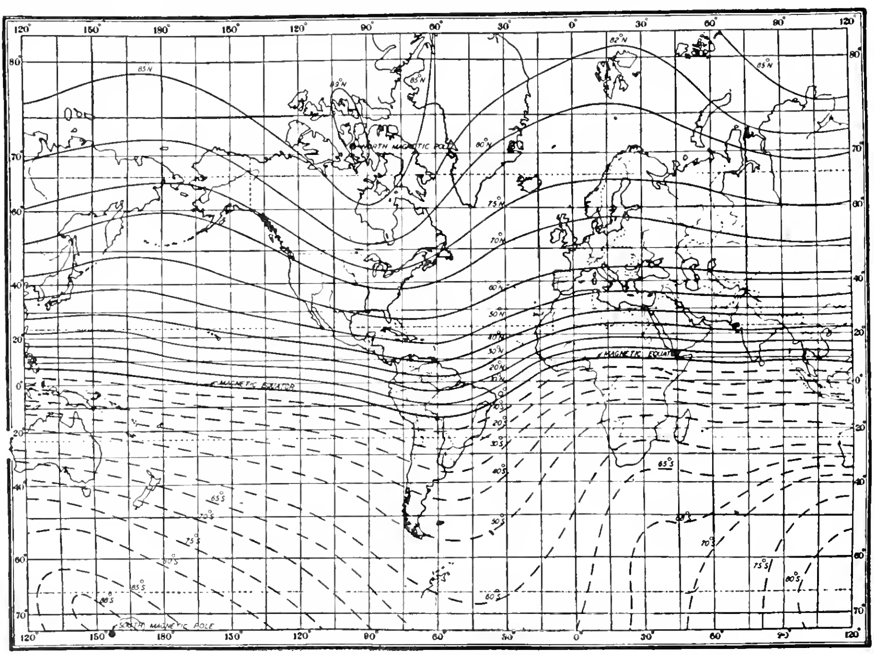
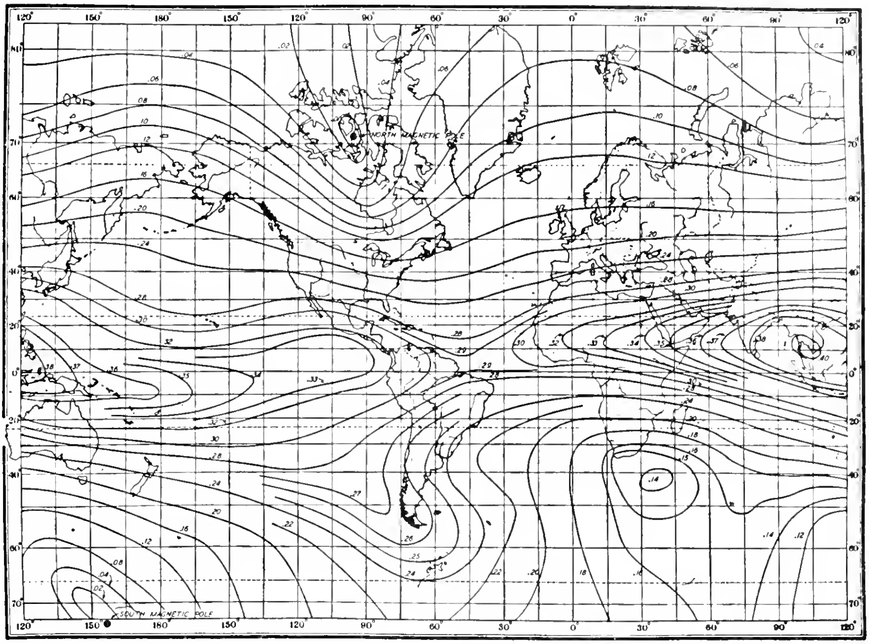


TABLE 727.—World Isoclinic Lines, Epoch 1930 (Lines of Equal Inclination (*I*)). Solid Lines Indicate North End Dipping; Broken, South End Dipping



TERRESTRIAL MAGNETISM

TABLE 728.—World Isodynamic Lines, Epoch 1930 (Lines of Equal Horizontal Intensity (H))



The annual changes in position of isomagnetic lines shown in Tables 726-728 are most conveniently represented by the isoporic charts, Tables 729-731. To these are added also similar charts showing lines of equal annual change in vertical force (Z) and total force (F), Tables 735 and 736. The difficulty of securing data suitably distributed over the entire surface of the earth is such that only approximate positions of isopors are known, although there is sufficient evidence to show that these positions change with relative rapidity especially near the foci of change. The rates of change of the magnetic elements and the accelerations in those rates can be derived for regions where there are magnetic observatories by reference to Table 737, "Mean annual values of magnetic elements at observatories."

TABLE 729.—World Isoporic Lines for D (Lines of Equal Annual Change) Approximate Epoch 1920-1925

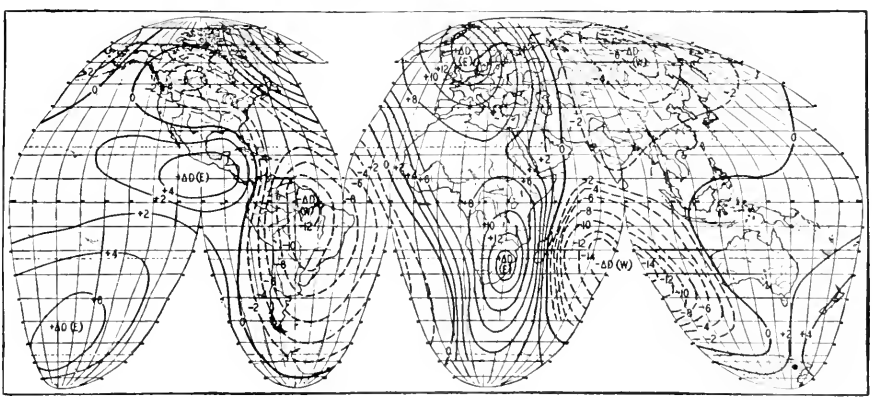


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TABLE 730.—World Isoporic Lines for *I* (Lines of Equal Annual Change) Approximate Epoch 1920-1925

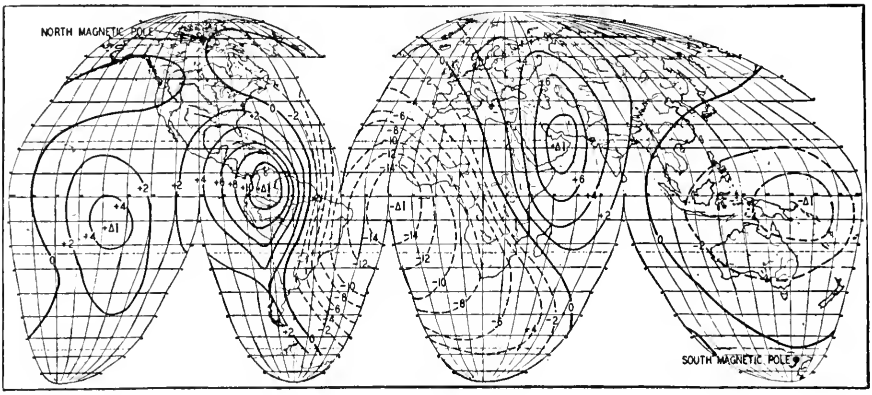
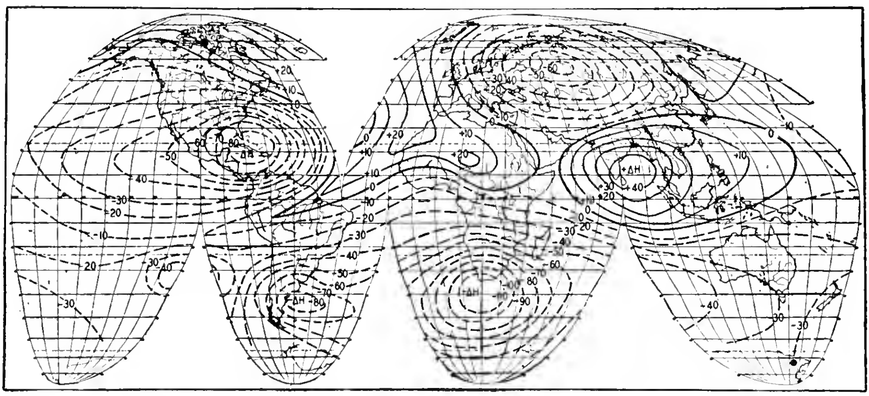


TABLE 731.—World Isoporic Lines for *H* (Lines of Equal Annual Change) Approximate Epoch 1920-1925



TERRESTRIAL MAGNETISM

APPROXIMATE VALUES FOR ANNUAL RATES OF SECULAR CHANGE IN THE MAGNETIC ELEMENTS DECLINATION (*D*), INCLINATION (*I*), AND HORIZONTAL INTENSITY (*H*) FOR THE EPOCH 1925[1]

(Because of the different intervals covered by available data and the known large accelerations in some parts, the values given for the annual secular-changes at intersections of parallels and meridians indicated are approximate except for those localities near magnetic observatories; in some cases there is great uncertainty and the values for these are enclosed in parentheses. The signs of the values given are in the algebraic sense for extrapolation considering east declination, north inclination, and horizontal intensity as positive and west declination and south inclination as negative.

TABLE 732.—Annual Change in Magnetic Declination (*D*)

Latitude	Longitude east of Greenwich																	
	0°	20°	40°	60°	80°	100°	120°	140°	160°	180°	200°	220°	240°	260°	280°	300°	320°	340°
°	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
60 N.	+13	+12	+ 7	0	− 3	−4	−6	−6	−4	−3	0	0	−2	−3	0	+ 5	+ 9	+12
40 N.	+10	+10	+ 7	0	− 3	−4	−3	−2	−2	0	+1	0	−1	−2	−4	− 2	+ 2	+ 8
20 N.	+ 8	+ 8	+ 4	− 1	− 3	−2	−1	−1	0	0	+2	+3	+4	+4	+1	− 6	− 4	+ 2
0	+ 6	+ 9	+ 8	− 6	− 5	−2	0	+1	+1	+1	+2	+2	+2	+3	0	−12	−12	− 2
20 S.	+ 2	+10	+10	−11	−14	−6	+1	+1	+2	+3	+3	+4	+3	+2	−3	−10	− 9	− 5
40 S.	0	+10	+ 9	− 4	−12	−7	0	+1	+3	+5	+6	+6	+4	+2	−3	− 8	− 7	− 4
60 S.	+ 2	+ 7	+ 6	+ 2	0	−1	−1	+1	+4	+6	+7	+6	+4	+2	+2	− 4	− 4	− 2

TABLE 733.—Annual Change in Magnetic Inclination (*I*)

°	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
60 N.	+ 1	+ 2	+ 3	+ 4	+ 3	+2	+2	+1	+1	+1	0	0	0	0	−1	− 2	− 2	0
40 N.	− 2	+ 1	+ 4	+ 7	+ 4	+2	+1	0	0	−1	−1	0	0	+1	+1	0	− 5	− 4
20 N.	− 6	− 1	+ 5	+ 8	+ 3	0	−1	−2	−2	−1	+1	+2	+1	+3	+7	+ 3	− 8	−11
0	−12	− 4	+ 4	+ 6	+ 1	−1	−3	−4	−4	−1	+1	+4	+2	+4	+9	+ 6	−10	−15
20 S.	−11	− 7	− 1	+ 2	+ 1	−1	−2	−4	−4	−2	0	+4	+2	+3	+5	0	−11	−14
40 S.	− 9	− 8	− 5	− 2	+ 1	0	−1	−2	−1	−1	0	+2	+2	+2	+2	− 1	− 7	−10
60 S.	− 6	− 6	− 5	− 3	0	0	0	0	−1	0	(+1)	(+1)	(+1)	(+1)	(+2)	+ 1	− 2	− 4

TABLE 734.—Annual Change in Magnetic Horizontal Intensity (*H*)

°	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
60 N.	−10	−30	−45	−60	−50	−40	−25	0	+10	+10	0	−10	− 5	0	+10	+20	+20	+ 5
40 N.	+ 5	−10	−25	−35	−35	−20	−10	0	0	−10	−15	−20	−25	−30	−40	−25	+ 5	+25
20 N.	+10	+15	0	+ 5	+35	+30	+15	+10	0	−20	−30	−35	−45	−60	−90	−60	0	+20
0	−25	−15	−10	0	+25	+25	+10	0	−10	−10	−15	−25	−30	−35	−25	− 5	0	−15
20 S.	−55	−70	−50	−40	−30	−20	−25	−25	−25	−20	−15	−15	−15	−20	−20	−25	−30	−40
40 S.	−95	−110	−95	−70	−50	−45	−35	−30	−30	−25	−20	−25	−25	−30	−50	−85	−70	−70
60 S.	(−70)	(−80)	(−80)	(−70)	(−60)	(−35)	(−30)	(−30)	−30	−15	−20	−20	−20	−30	−45	−50	−60	−65

[1] Prepared by H. W. Fisk, of the Department of Terrestrial Magnetism, Carnegie Institution of Washington.

TERRESTRIAL MAGNETISM

TABLE 735.—World Isoporic Lines for Vertical Intensity (Lines of Equal Annual Change) Approximate Epoch 1920-1925

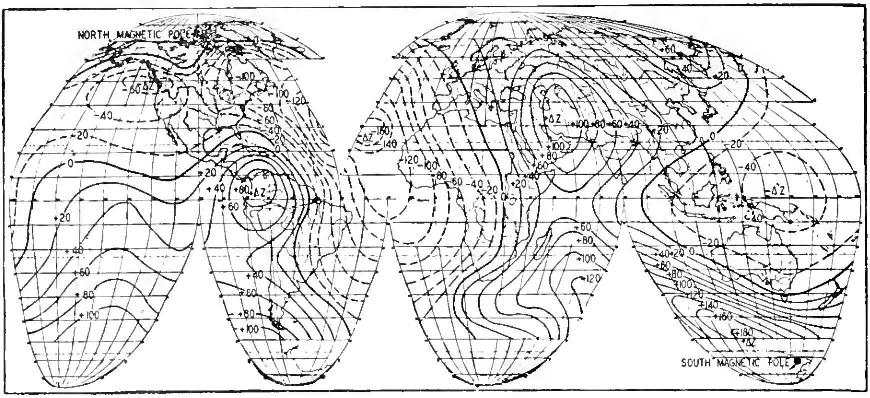


TABLE 736.—World Isoporic Lines for Total Intensity (Lines of Equal Annual Change) Approximate Epoch 1920-1925

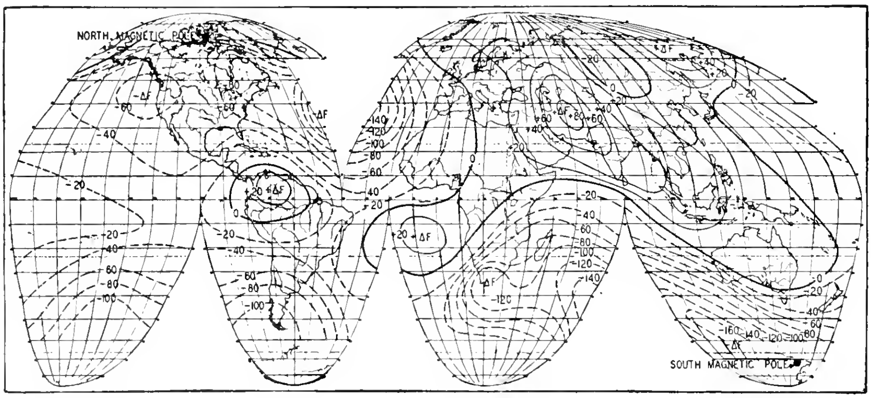


Table 737

MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES

In order to show the change of the annual rates of secular variation with geographical position and with time and the accelerations in those rates without unduly extending the tables, the values of the elements have been given for each fifth year beginning with 1900, and for consecutive years from 1925 or 1930. When the observatory was established subsequent to 1900, values obtained during the first year of the operation are given.

The lack of uniformity in the distribution of magnetic observatories should be taken into account. The satisfactory computation of the so-called magnetic constants of the earth, the investigation of the laws of secular variation and daily variation, the study of the manner of propagation of magnetic storms and their relation to other world-wide phenomena, require additional observatories in the southern hemisphere, specifically in Africa, and on favorably located islands in the southern Pacific and Atlantic oceans.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Matotchkin Shar	73 16 N.	56 24 E.	1924	20 37.5 E.	80 05.4 N.	.09491	.54326
Sodankylä	67 22 N.	26 39 E.	1915	0 27.2 E.	75 22.1 N.	.12853	.49232
			1920	1 04.1 E.	75 35.8 N.	.12638	.49211
			1925	1 53.2 E.	75 48.4 N.	.12440	.49186
			1930	2 35.5 W.	76 02.4 N.	.12228	.49216
			1931	2 45.0 W.	76 05.0 N.	.12188	.49220
Godhavn	65 15 N.	53 30 W.	1927	58 28.4 W.	81 34.7 N.	.08259	.55788
Lerwick	60 08 N.	1 11 W.	1923[b]	15 44.5 W.	72 33.6 N.	.14655	.46650
			1925[b]	15 17.7 W.	72 37.2 N.	.14621	.46712
			1926	15 02.8 W.	72 37.1 N.	.14618	.46699
			1930	14 11.2 W.	72 41.6 N.	.14527	.46624
			1931	13 59.6 W.	72 42.3 N.	.14517	.46623
Pavlovsk (Sloutzk)	59 41 N.	30 29 E.	1900	0 37.6 E.	70 37.4 N.	.16548	.47050
			1905	0 59.8 E.	70 36.1 N.	.16540	.46975
			1910	1 30.0 E.	70 41.9 N.	.16420	.46882
			1915	2 06.8 E.	70 54.9 N.	.16210	.46850
			1920	2 42.7 E.	71 11.2 N.	.15978	.46897
			1925	3 25.3 E.	71 27.1 N.	.15770	.47000
			1927	3 42.6 E.	71 34.8 N.	.15675	.47068
			1928	3 50.2 E.	71 38.6 N.	.15630	.47106
			1929	3 57.4 E.	71 42.3 N.	.15586	.47145
Lovö	59 21 N.	17 50 E.	1928	3 18.6 W.	....	.15617	.....
			1929	3 08.3 W.	71 24.9 N.	.15584	.46344
Sitka	57 03 N.	135 20 W.	1902	29 51.1 E.	74 47.8 N.	.15441	.56822
			1905	29 59.1 E.	74 43.2 N.	.15494	.56719
			1910	30 16.4 E.	74 32.2 N.	.15577	.56312
			1915	30 23.2 E.	74 26.5 N.	.15593	.56008
			1920	30 28.2 E.	74 22.1 N.	.15574	.55662
			1925	30 27.0 E.	74 22.0 N.	.15528	.55491
			1928	30 20.0 E.	74 22.4 N.	.15485	.55357
			1929	(30 17.7 E.)	(74 22.7 N.)	(.15465)	(.55307)
			1930	(30 15.6 E.)	(74 22.8 N.)	(.15448)	(.55255)
			1931	(30 13.1 E.)	(74 23.5 N.)	(.15454)	(.55190)
Katharinenburg (Swerdlovsk)	56 50 N.	60 38 E.	1900	10 04.0 E.	70 40.3 N.	.17789	.50718
			1905	10 27.2 E.	70 48.3 N.	.17692	.50819
			1910	10 48.7 E.	71 00.7 N.	.17476	.50786
			1915	11 02.6 E.	71 21.2 N.	.17142	.50797
			1920	11 01.9 E.	71 42.1 N.	.16812	.50843
			1925	11 01.0 E.	72 03.0 N.	.16513	.50974
			1927	10 59.5 E.	72 12.2 N.	.16389	.51053
			1929	(10 57.2 E.)	(72 20.3 N.)	(.16285)	(.51145)
Rude Skov	55 51 N.	12 27 E.	1907	9 48.4 W.	68 44.0 N.	.17423	.44765
			1910	9 27.1 W.	68 45.0 N.	.17375	.44648
			1915	8 42.7 W.	68 50.6 N.	.17257	.44591
			1920	7 55.6 W.	68 59.6 N.	.17124	.44596
			1925	6 57.7 W.	69 07.2 N.	.17025	.44631
			1930	6 00.4 W.	69 19.0 N.	.17893	.44747
			1931	5 50.4 W.	69 20.5 N.	.17879	.44747
Kasan (Saimistsche)	55 50 N.	48 51 E.	1915[b]	8 24.3 E.	69 28.8 N.	.17829	.47635
			1920[b]	8 39.6 E.[c]	69 48.1 N.[c]	.17530[c]	.47650[c]
			1925	8 57.0 E.	70 12.2 N.	.17260	.47951
			1930	9 06.8 E.	70 36.3 N.	.16082	.48238
			1931	9 07.3 E.	70 30.1 N.	.16953	.48279
Koutchíno	55 46 N.	37 58 E.	1926	6 25.9 E.	68 51.1 N.	.17965	.46442
			1927	6 36.1 E.	68 59.5 N.	.17875	.46545
Eskdalemuir	55 19 N.	3 12 W.	1908[d]	18 33.3 W.	69 37.3 N.	.16830	.45307
			1910[b]	18 23.3 W.	69 37.8 N.	.16836	.45343
			1915	17 35.9 W.	69 36.0 N.	.16786	.45173
			1920	16 49.7 W.	69 39.5 N.	.16706	.45062
			1925	15 48.4 W.	69 39.3 N.	.16665	.44943
			1930	14 47.1 W.	69 43.2 N.	.16585	.44881
			1931	14 38.4 W.	69 43.7 N.	.16583	.44898

[a] See also tables for previous and intermediate years in Terr. Mag., 4, 135; 5, 128; 8, 7; 12, 175; 16, 209; 20, 131; 22, 169; 23, 191; 25, 179; 26, 147; 27, 157; 29, 149; 31, 27; 32, 27; 33, 95; and 35, 165. Unless otherwise indicated values are from continuous magnetograph records. Preliminary values, pending final reductions, are indicated by parentheses. Observatories marked by an asterisk (*) are in regions of local disturbance. [b] Values from absolute observations only. [c] No observations in February and March. [d] Absolute observations during June and July only.

MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Meanook	54 37 N.	113 20 W.	1916[e]	27 46.7 E.	77 55.2 N.[b]	.12944[b]	.60481[b]
			1920	27 38.6 E.	77 53.6 N.[b]	.12923[b]	.60246[b]
			1925[f]	27 10.7 E.	77 53.8 N.[b]	.12852[b]	.59934[b]
			1926	27 04.2 E.	77 53.8 N.[b]	.12832[b]	.59844[b]
			1928	26 48.5 E.	77 54.6 N.[b]	.12790	.59719[b]
			1930	26 39.2 E.	77 56.1 N.[b]	.12755	.59675[b]
Stonyhurst	53 51 N.	2 28 W.	1900	18 10.9 W.	68 50.3 N.[b]	.17312	.44720
			1905	17 53.5 W.	68 46.5 N.[b]	.17368	.44718
			1910	17 20.0 W.	68 42.2 N.[b]	.17407	.44605
			1915	16 38.0 W.	68 41.4 N.[b]	.17342	.44457
			1920	15 52.9 W.	68 43.5 N.[b]	.17303	.44433
			1925	14 53.4 W.	68 42.2 N.[b]	.17263	.44282
			1926	14 39.7 W.	68 44.6 N.[b]	.17240	.44316
			1927	14 26.5 W.	68 43.5 N.[b]	.17231	.44251
			1928	14 14.5 W.	68 46.5 N.[b]	.17209	.44310
			1929	14 03.1 W.	68 46.2 N.[b]	.17201	.44275
			1930	13 51.1 W.[a]	68 47.8 N.[b]	.17190[a]	.44311[b]
			1931	13 39.4 W.[a]	68 47.3 N.[b]	.17181[a]	.44271[b]
Wilhelmshaven	53 32 N.	8 09 E.	1900	12 27.7 W.	67 44.0 N.	.18095	.44193
			1905	12 08.2 W.	67 40.2 N.	.18169	.44235
			1910	11 37.0 W.	67 30.5 N.	.18124	.43773
			1911	11 28.2 W.	67 30.7 N.[b]	.18110	.43747
Irkutsk* (Zouy)	52 28 N.	104 02 E.	1916	1 20.7 E.	71 02.5 N.	.19396	.56463
			1920	1 02.3 E.	71 06.6 N.	.19277	.56337
			1925	0 45.5 E.	71 15.6 N.	.19070	.56212
			1926	0 42.9 E.	71 16.8 N.	.19025	.56141
			1928	0 30.6 E.	71 17.8 N.	.19061	.56303
			1929	0 20.2 E.	71 19.2 N.	.19038	.56310
Potsdam	52 23 N.	13 04 E.	1900	9 56.3 W.	66 24.2 N.	.18844	.43138
			1905	9 34.5 W.	66 19.3 N.	.18879	.43050
			1910	9 02.9 W.	66 19.7 N.	.18828	.42948
			1915	8 17.1 W.	66 25.1 N.	.18726	.42899
			1920	7 29.4 W.	66 33.5 N.	.18606	.42912
			1925	6 33.0 W.	66 39.7 N.	.18532	.42951
			1926	6 20.6 W.	66 42.6 N.	.18503	.42982
			1927	6 09.1 W.	66 44.0 N.	.18489	.43012
			1928	5 58.2 W.	66 45.8 N.	.18467	.43010
			1929	(5 47.8 W.)	(66 48.6 N.)	(.18442)	(.43049)
Seddin	52 17 N.	13 01 E.	1908	9 19.2 W.	66 16.2 N.	.18890	.42974
			1910	9 04.3 W.	66 16.6 N.	.18866	.42933
			1915	8 18.6 W.	66 22.1 N.	.18765	.42885
			1920	7 31.2 W.	66 30.6 N.	.18645	.42899
			1925	6 34.7 W.	66 36.8 N.	.18570	.42938
			1926	6 22.3 W.	66 39.7 N.	.18539	.42968
			1927	6 10.9 W.	66 41.1 N.	.18526	.42987
			1928	5 59.6 W.	66 42.8 N.	.18505	.42995
			1929	5 49.1 W.	66 45.6 N.	.18480	.43034
			1930	5 38.6 W.	66 48.3 N.	.18456	.43072
			1931	(5 28.9 W.)	(66 49.8 N.)	(.18450)	(.43108)
Irkutsk[g] (Old site)	52 16 N.	104 16 E.	1900	2 01.3 E.	70 14.8 N.	.20129	.56053
			1905	1 58.1 E.	70 25.0 N.	.20011	.56250
			1910	1 47.0 E.	70 36.0 N.	.19824	.56293
			1915	1 27.0 E.	70 45.8 N.	.19621	.56228
			1920	1 02.8 E.	70 51.9 N.	.19458	.56081
Swider[b]	52 07 N.	21 15 E.	1921	3 30.3 W.	66 34.4 N.	.18712	.43185
			1925	2 46.6 W.	66 45.0 N.	.18620	.43339
			1926	2 35.1 W.	66 48.3 N.	.18584	.43369
			1927	2 25.2 W.	66 50.3 N.	.18563	.43390
			1928	2 15.3 W.	66 54.2 N.	.18536	.43464
			1929	2 06.3 W.	66 57.6 N.	.18507	.43517
			1930	1 49.1 W.	67 03.2 N.	.18463	.43608
De Bilt	52 06 N.	5 11 E.	1900	13 50.6 W.	66 57 N.	.18508	.4349
			1905	13 28.5 W.	66 48.5 N.	.18560	.4332
			1910	12 58.2 W.	66 46.5 N.	.18541	.43208
			1915	12 12.5 W.	66 48.0 N.	.18481	.43117
			1920	11 24.2 W.	66 51.8 N.	.18397	.43056
			1925	10 25.4 W.	66 53.5 N.	.18359	.43026
			1926	10 13.1 W.	66 55.5 N.	.18337	.43040
			1927	10 01.0 W.	66 55.9 N.	.18330	.43041
			1928	9 48.8 W.	66 57.4 N.	.18313	.43053
			1929	9 37.3 W.	66 58.6 N.	.18300	.43063
			1930	9 26.3 W.	67 00.4 N.	.18282	.43084
			1931	9 15.7 W.	67 00.8 N.	.18278	.43089

[e] Last 4 months only. [f] No values in September. [g] 1915, New site at Zouy; values for 1915, 1920 determined from Zouy by applying corrections, D, $+0'.5$(E); I, $-14'.7$; H, $+181\gamma$. [b] Built in 1914; World War prevented operation until 1921.

MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Valencia[b] (Cahirciveen)	51 56 N.	10 15 W.	1900	21 30.0 W.	68 29.6 N.	.17765	.45082
			1905	21 10.4 W.	68 19.2 N.	.17848	.44893
			1910	20 44.6 W.	68 13.0 N.	.17892	.44771
			1915	20 03.8 W.	68 07.9 N.[i]	.17869	.44519[i]
			1920	19 17.9 W.	68 05.3 N.	.17840	.44353
			1925	18 22.4 W.	68 00.0 N.	.17849	.44177
			1930	17 27.6 W.	67 59.8 N.	.17813	.44081
			1931	17 16.8 W.	67 58.7 N.	.17815	.44048
Bochum	51 29 N.	7 14 E.	1900	12 47.2 W.	....	......	......
			1905	12 27.2 W.	....	......	......
			1910	11 56.4 W.	....	......	......
			1915	11 08.9 W.[j]	....	......	......
			1920	10 19.9 W.	....	......	......
			1925	9 25.9 W.	....	......	......
			1930	8 35.2 W.[b]	....	......	......
			1931	8 23.8 W.[b]	....	......	......
Kew	51 28 N.	0 19 W.	1900	16 52.7 W.	67 11.8 N.	.18422	.43818
			1905	16 32.9 W.	67 03.8 N.	.18504	.43727
			1910	16 03.2 W.	66 58.7 N.	.18503	.43546
			1915	15 18.4 W.	66 56.6 N.	.18463	.43376
			1920	14 31.0 W.	66 57.9 N.	.18410	.43297
			1924	13 45.1 W.	66 56.5 N.	.18392	.43205
Greenwich[k]	51 28 N.	0 00	1900	16 29.0 W.	67 08.8 N.	.1846	.4380
			1905	16 09.9 W.	66 56.3 N.	.1854	.4355
			1910	15 41.2 W.	66 52.8 N.	.1855	.4344
			1915	14 56.5 W.	66 52.0 N.	.1851	.4333
			1920	14 08.6 W.	66 53.6 N.	.18454	.43249
			1925	13 09.9 W.	66 51.4 N.	.18414	.43080
Abinger	51 11 N.	0 23 W.	1925[l]	13 22.7 W.	66 35.1 N.	.18597	.42946
			1926	13 10.4 W.	66 36.3 N.	.18581	.42947
			1927	12 58.4 W.	66 36.2 N.	.18575	.42932
			1928	12 47.0 W.	66 37.3 N.	.18564	.42941
			1929	12 35.8 W.	66 37.2 N.	.18555	.42918
			1930	12 24.6 W.	66 38.2 N.	.18542	.42924
			1931	12 13.7 W.	66 38.1 N.	.18544	.42923
Uccle	50 48 N.	4 21 E.	1900	14 13.6 W.	66 09.8 N.	.18952	.42896
			1905	13 53.7 W.	66 03.8 N.	.19069	.42956
			1910	13 22.2 W.	66 00.8 N.	.19028	.42764
			1915	12 38.3 W.	66 01.2 N.[m]	.18989	.42690[m]
			1920	11 50.6 W.	66 04.1 N.	......	......
			1925	10 52.7 W.	....	......	......
			1930	9 54.6 W.	....	......	......
Hermsdorf	50 46 N.	16 14 E.	1901	8 13.6 W.[n]	....	......	......
			1905	7 55.0 W.	....	......	......
			1910	7 23.9 W.	....	......	......
			1915	6 37.8 W.	....	......	......
			1920	5 53.1 W.	....	......	......
			1925	4 54.3 W.	....	......	......
			1929	4 10.6 W.	....	......	......
Beuthen	50 21 N.	18 55 E.	1900	6 53.7 W.	....	......	......
			1905	6 27.9 W.	....	......	......
			1908	6 12.3 W.	....	......	......
Beuthen-Mikilow	50 09 N.	18 54 E.	1925	3 37.8 W.	....	......	......
			1926	3 26.7 W.	....	......	......
			1927	3 16.0 W.	....	......	......
			1928	3 06.2 W.	....	......	......
			1929	2 56.6 W.	....	......	......
			1930	2 46.7 W.	....	......	......
Falmouth[o]	50 09 N.	5 05 W.	1900	18 29.1 W.	66 45.2 N.[b]	.18689	.43507[b]
			1905	18 08.4 W.	66 36.1 N.	.18749	.43328
			1910	17 41.6 W.	66 29.1 N.	.18802	.43208
			1912	17 24.2 W.	66 26.6 N.	.18799	.43118
Prague	50 05 N.	14 25 E.	1902	8 57.6 W.	....	.19903	......
			1905	8 43.3 W.	....	......	......
			1910	8 09.6 W.	....	......	......
			1915	7 24.2 W.	....	......	......
			1920	6 35.6 W.	....	......	......
			1925	5 39.9 W.	....	......	......
			1926	5 27.7 W.	....	......	......
Cracow	50 04 N.	19 58 E.	1907	5 47.9 W.	....	......	......
			1910	5 27.4 W.	....	......	......
			1913	5 03.3 W.	64 18.4 N.	......	......

[i] 11 months, no observations in May. [j] Mean values from magnetograms at 8^h and 14^h daily; other values given are means of all hourly scalings. [k] Because of electric railway, superseded in 1926 by observatory at Abinger. [l] Means, 10 months, February to November. [m] Mean, 10 months, January to October. [n] Magnetograph for D only. [o] Discontinued in 1912.

MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES

Observatory	Latitude	Longitude	Year	Declination (*D*)	Inclination (*I*)	Intensity Hor. (*H*)	Intensity Ver. (*Z*)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Val Joyeux	48 49 N.	2 01 E.	1901	15 12.0 W.	64 58.9 N.	.19680	.42167
			1905	14 55.7 W.	64 50.7 N.	.19728	.42008
			1910	14 25.7 W.	64 43.0 N.	.19738	.41789
			1915	13 40.5 W.	64 38.8 N.	.19715	.41607
			1920	12 53.0 W.	64 41.6 N.	.19666	.41591
			1925	11 55.8 W.	64 38.7 N.	.19659	.41485
			1930	10 59.3 W.	64 42.0 N.	.19631	.41529
			1931	10 49.0 W.	64 43.4 N.	.19636	.41584
Maisach	48 12 N.	11 15 E.	1927	6 52.5 W.	63 32.5 N.	.20314	.40817
			1930	6 20.2 W.	63 39.7 N.	.20279	.40963
			1931	6 12.2 W.	63 41.1 N.	.20288	.41022
Munich	48 09 N.	11 37 E.	1900	10 27.9 W.	63 18.5 N.[b]	.20610	.40993
			1905	10 04.3 W.	63 10.2 N.[b]	.20651	.40828
			1910	9 31.5 W.	63 08.4 N.[b]	.20638	.40750
			1915	8 49.3 W.	....	......	......
			1920	8 03.8 W.	....	......	......
			1925	7 06.7 W.	....	......	......
			1926	6 54.7 W.	....	......	......
Ó-Gyalla	47 53 N.	18 12 E.	1900	7 28.8 W.	....	......	......
(Pesth)			1905	7 03.0 W.	....	.21151	......
			1910	6 34.5 W.	62 31.2 N.	.21082	.40532
			1915	5 49.3 W.	....	.20995	......
			1918	5 21.1 W.	....	.20917	......
Ó-Gyalla	47 52 N.	8 11 E.	1924	4 18.6 W.	....	......	......
(Stara Dala)			1925	4 08.9 W.	....	......	......
			1926	3 57.2 W.	....	......	......
			1928	3 36.7 W.	....	......	......
			1930	3 18.8 W.	....	......	......
Nantes[p]	47 15 N.	1 34 W.	1923	13 23.5 W.	63 45.8 N.	.20212	.41009
			1924	13 11.6 W.	63 41.6 N.	.20240	.40940
			1925	12 59.6 W.	63 39.0 N.	.20234	.40850
			1926	12 48.2 W.	63 40.3 N	.20227	.40876
			1928	12 23.6 W.	63 41.2 N.	.20220	.40886
			1930	12 04.6 W.	63 43.3 N.	.20226	.40965
			1931	11 54.6 W.	63 43.3 N.	.20241	.40995
Otomari[b]	46 39 N.	142 46 E.	1920	8 11.3 W.	....	......	......
			1925	8 25.9 W.	....	......	......
			1926	8 29.0 W.	....	......	......
			1927	8 30.8 W.	....	......	......
			1928	8 32.6 W.	....	......	......
			1929	8 34.8 W.	....	......	......
Odessa	46 26 N.	30 46 E.	1900[m]	4 29.9 W.	62 18.0 N.	.21876	.41659
			1910	3 35.9 W.	62 26.9 N.	.21707	.41606
			1925	1 36.4 W.	63 18.9 N.	.21213	.42206
Pola	44 52 N.	13 51 E.	1900	9 25.8 W.	60 15.9 N.	.22192	.38852
			1905	9 00.1 W.	60 07.6 N.	.22227	.38695
			1910	8 28.0 W.	60 04.7 N.	.22194	.38562
			1915	7 39.0 W.	60 05.1 N.	.22166	.38526
			1919	7 01.6 W.	60 09.3 N.	.22111	.38539
			1921[q]	6 38.6 W.	60 10.3 N.	.22094	.38537
			1922	6 28.0 W.	60 12.8 N.	.22090	.38591
Agincourt	43 47 N.	79 16 W.	1900	5 28.8 W.	74 31.6 N.	.16497	.59594
			1905	5 43.1 W.	74 33.4 N.	.16411	.59404
			1910	6 04.8 W.	74 38.6 N.	.16248	.59163
			1915	6 29.4 W.	74 42.8 N.	.16034	.58664
			1920	6 45.4 W.	74 44.6 N.	.15865	.58166
			1925	7 09.7 W.	74 44.2 N.	.15727	.57628
			1926	7 13.4 W.	74 44.6 N.	.15692	.57527
			1927	7 16.4 W.	74 44.3 N.	.15664	.57412
			1928	7 20.3 W.	74 44.9 N.	.15628	.57315
			1929	7 24.0 W.	74 45.4 N.	.15586	.57196
			1930	7 28.1 W.	74 46.4 N.	.15544	.57103
			1931	7 31.9 W.	74 46.3 N.	.15520	.57010
Karsani	41 50 N.	44 42 E.	1926	4 12.3 E.	58 03.0 N.	.24694	.39595
(New site)			1927	4 15.5 E.	58 08.1 N.	.24673	.39693
			1928	4 18.8 E.	58 13.5 N.	.24646	.39788
			1929	4 19.7 E.	58 19.0 N.	.24627	.39901
Tiflis	41 43 N.	44 48 E.	1900	2 16.4 E.	55 53.2 N.	.25594	.37783
(Karsani,			1905	2 41.6 E.	56 02.8 N.	.25451	.37709
old site)			1910	2 52.7 E.	56 35.5 N.	.25343	.37422
			1913	3 09.1 E.	56 51.1 N.	.25217	.37612

[p] Electrical disturbances, especially in Z. [q] No observations during 1920 to August, 1921; values for 1921 are for four months, September to December.

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Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Capodimonte (Naples)	40 52 N.	14 15 E.	1900	9 10.2 W.	56 23.8 N.	.24133	.36318
			1905	8 45.3 W.	56 15.0 N.	.24164	.36164
			1910	8 13.0 W.	56 11.9 N.	.24160	.36088
			1922	(6 25.7 W.)	(57 02.6 N.)	(.23705)	(.36563)
Ebro (Tortosa)	40 49 N.	0 31 E.	1905	13 56.9 W.	58 07.6 N.	.23230	.37359
			1910	13 25.9 W.	57 57.3 N.	.23251	.37145
			1915	12 46.0 W.	57 47.1 N.	.23277	.36941
			1920	11 59.3 W.	57 39.4 N.	.23291	.36781
			1925	11 08.8 W.	57 28.4 N.	.23367	.36642
			1928	10 37.7 W.	57 26.8 N.	.23386	.36633
			1930	10 20.1 W.	57 25.3 N.	.23401	.36621
			1931	10 11.7 W.	57 24.1 N.	.23415	.36616
Coimbra	40 12 N.	8 25 W.	1900	17 20.1 W.	59 24.3 N.	.22768	.38506
			1905	17 01.5 W.	59 06.4 N.	.22900	.38273
			1910	16 34.5 W.	58 50.1 N.	.22986	.38006
			1915	15 57.5 W.	58 34.7 N.	.23053	.37734
			1920	15 21.5 W.	58 22.8 N.	.23087	.37496
			1925	14 38.2 W.	58 13.9 N.	.23143	.37368
			1930[b]	13 55.3 W.	57 56.4 N.	.23179	.37001
			1931[b]	13 45.5 W.	57 52.2 N.	.23196	.36931
Baldwin[r]	38 47 N.	95 10 W.	1901	8 21.9 E.	68 34.5 N.	.21931	.55890
			1905	8 27.6 E.	68 43.0 N.	.21821	.56016
			1909[s]	8 34.0 E.	68 50.2 N.	.21644	.55908
Cheltenham	38 44 N.	76 50 W.	1901[t]	5 05.0 W.	70 21.5 N.	.20195	.56586
			1905	5 17.8 W.	70 25.4 N.	.20064	.56418
			1910	5 41.4 W.	70 35.4 N.	.19806	.56209
			1915	6 04.0 W.	70 46.8 N.	.19417	.55694
			1920	6 18.5 W.	70 55.4 N.	.19118	.55285
			1925	6 39.4 W.	71 00.2 N.	.18874	.54824
			1930	6 55.9 W.	71 08.0 N.	.18591	.54402
			1931	(7 00.2 W.)	(71 09.3 N.)	(.18530)	(.54317)
			1932	(7 03.8 W.)	(71 11.2 N.)	(.18485)	(.54247)
Athens	37 59 N.	23 42 E.	1900	5 42.3 W.	52 07.7 N.	.26063	.33514
			1905	5 18.2 W.	52 09.5 N.	.26140	.33598
			1908	4 53.0 W.	52 11.7 N.	.26197	.33613
San Miguel* (Ponta Delgada)	37 46 N.	25 39 W.	1913	19 53.2 W.[b]	60 49.5 N.[b]	.23059[b]	.41283[b]
			1915	19 53.2 W.[b]	60 49.5 N.[b]	.23059[b]	.41282[b]
			1920	19 20.2 W.	60 26.0 N.[b]	.23123[b]	.40759[b]
			1925	18 56.5 W.	60 03.0 N.[b]	.23256[b]	.40378[b]
			1930	18 29.4 W.	59 46.6 N.[b]	.23310[b]	.40004[b]
			1931	18 23.1 W.	59 41.1 N.[b]	.23351[b]	.39936[b]
Zinsen[b]	37 30 N.	126 38 E.	1918	5 41.0 W.	......	......	......
			1926	5 57.8 W.	53 09 N.	......	......
			1927	5 59.1 W.	53 08 N.	.29971	......
			1928	6 00.8 W.	53 13 N.	.29965	......
			1929	6 02.4 W.	53 16.1 N.	.29923	.40099
			1930	6 03.8 W.	53 08 N.	.29831	......
			1931	6 03.9 W.	53 12 N.	.29866	......
San Fernando	36 28 N.	6 12 W.	1900	15 59.3 W.	55 09.2 N.[b]	.24631	.35378
			1905	15 40.3 W.	54 54.2 N.[b]	.24762	.35237
			1910	15 13.6 W.	54 38.1 N.[b]	.24879	.35053
			1915	14 36.0 W.	54 19.1 N.[b]	.24978	.34784
			1920	14 01.0 W.	53 37.5 N.[b](?)	.25021	.33969(?)
			1925	13 15.1 W.	53 40.0 N.[b]	.25032	.34035
			1930	12 32.8 W.	53 29.9 N.[b]	.25072	.33881[b]
			1931	12 25.9 W.	53 27.9 N.[b]	.25106	.33885[b]
Kakioka[u]	36 14 N.	140 11 E.	1913	5 10.1 W.	49 30.0 N.	.29749	.34851
			1914	5 12.9 W.	49 29.8 N.	.29783	.34868
			1915	5 15.6 W.	49 31.3 N.	.29752	.34863
			1916	5 17.6 W.	49 31.7 N.	.29743	.34859
			1924	5 31.6 W.	49 29.5 N.	.29708	.34774
			1925	5 34.4 W.	49 27.8 N.	.29716	.34749
			1926	5 36.6 W.	49 27.7 N.	.29694	.34721
			1928	5 40.5 W.	49 27.0 N.	.29707	.34721
			1930	5 42.4 W.	49 27.9 N.	.29713	.34746
Tsingtao	36 04 N.	120 19 E.	1916	4 04.7 W.	52 07.1 N.	.30842	.39644
			1920	4 12.9 W.	52 07.0 N.	.30817	.39610
			1925	4 22.6 W.	52 05.9 N.	.30831	.39603
			1930	4 32.8 W.	52 06.8 N.	.30868	.39673
			1931	4 32.1 W.	52 05.1 N.	.30880	.39646

[r] Superseded by Tucson, October, 1909. [s] Means, 10 months, January to October. [t] Means, 6 months July to December. [u] Destroyed by earthquake, September 1, 1923; all records, January, 1917 to August, 1923, lost by fire.

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Observatory	Latitude	Longitude	Year	Declination (*D*)	Inclination (*I*)	Intensity Hor. (*H*)	Intensity Ver. (*Z*)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Tokyo[v]	35 41 N.	139 45 E.	1900	4 33.7 W.	49 00.7 N.	.29909	.34421
			1905	4 46.2 W.	48 56.1 N.	.29952	.34376
			1910	4 58.2 W.	49 07.3 N.	.30007	.34668
			1912	5 03.4 W.	48 53.7 N.	.29996	.34379
Tucson	32 15 N.	110 50 W.	1910	13 25.8 E.	59 19.6 N.	.27379	.46160
			1915	13 42.5 E.	59 24.7 N.	.27119	.45879
			1920	13 48.0 E.	59 27.6 N.	.26910	.45610
			1925	13 45.2 E.	59 30.3 N.	.26698	.45334
			1930	(13 47.7 E.)	(59 37.0 N.)	(.26432)	(.45081)
			1931	(13 49.5 E.)	(59 37.5 N.)	(.26398)	(.45038)
Lukiapang	31 19 N.	121 02 E.	1909	2 58.6 W.	45 34.8 N.	.33187	.33879
			1910	3 01.1 W.	45 34.3 N.	.33201	.33883
			1915	3 13.2 W.	45 32.1 N.	.33190	.33839
			1920	3 21.4 W.	45 30.7 N.	.33155	.33773
			1925[b]	3 30.5 W.	45 28.3 N.	.33160	.33709
			1930	(3 37.4 W.)[b]	(45 25.1 N.)[b]	(.33264)[b]	(.33753)[b]
			1931	(3 37.0 W.)[b]	(45 22.5 N.)[b]	(.33313)[b]	(.33751)[b]
Zikawei[w]	31 12 N.	121 26 E.	1900	2 22.2 W.	45 45.5 N.	.32859	.33741
			1905	2 30.3 W.	45 37.1 N.	.33009	.33729
			1907	2 33.6 W.	45 36.6 N.	.33056	.33768
Dehra-Dun	30 19 N.	78 03 E.	1903	2 41.6 E.	43 14 N.	.33430	.31429
			1905	2 39.9 E.	43 24.2 N.	.33383	.31572
			1910	2 31.9 E.	43 54.8 N.	.33257	.32019
			1915	2 15.5 E.	44 30.6 N.	.33083[x]	.32522[x]
			1920	1 52.0 E.	44 59.9 N.	.32951	.32949
			1925	1 30.5 E.	45 21.0 N.	.32948	.33353
			1930	1 11.9 E.	45 34.5 N.	.32963	.33631
			1931	(1 08.6 E.)	(45 35.9 N.)	(.33001)	(.33698)
Helwan	29 52 N.	31 20 E.	1903[b]	3 21.4 W.	40 31.2 N.	.30209	.25819
			1905[b]	3 12.7 W.	40 36.2 N.	.30159	.25852
			1910	2 41.5 W.	40 40.5 N.	.30029	.25806
			1915	2 03.0 W.	40 54.8 N.	.30012	.26009
			1920	1 23.7 W.	41 12.8 N.	.29956	.26236
			1925	0 44.8 W.	41 25.7 N.	.29986	.26463
			1930	(0 14.7 W.)[b]	(41 43.8 N.)[b]	(.30078)[b]	(.26827)[b]
			1931	(0 10.5 W.)[b]	(41 45.6 N.)[b]	(.30126)[b]	(.26898)[b]
Taihoku[b]	25 02 N.	121 31 E.	1919	1 56.4 W.	....	......	......
			1920	1 57.5 W.	....	......	......
			1925	2 04.9 W.	....	......	......
			1926	2 06.4 W.	....	......	......
			1927	2 07.6 W.	....	......	......
			1928	2 08.6 W.	....	......	......
			1929	2 08.6 W.	....	......	......
Barrackpore[y]	22 46 N.	88 22 E.	1904	1 22.4 E.	30 20.0 N.	.37224	.21781
			1905	1 18.0 E.	30 22.5 N.	.37242	.21828
			1910	0 55.5 E.	30 42.2 N.	.37329	.22168
			1914	0 32.2 E.	30 58.9 N.	.37403	.22459
Au Tau[b,z]	22 27 N.	114 03 E.	1927[aa]	0 44.4 W.	....	.37433	......
			1928	0 43.1 W.	30 38.8 N.	.37478	.22207
			1929	0 43.5 W.	30 38.7 N.	.37481	.22206
			1930	0 43.6 W.	30 37.3 N.	.37485	.22187
			1931	0 43.3 W.	30 34.4 N.	.37522	.22164
Hong Kong[bb]	22 18 N.	114 10 E.	1900	0 18.5 E.	31 24.7 N.	.36728	.22430
			1905	0 08.9 E.	31 06.6 N.	.36975	.22317
			1910	0 00.4 E.	30 58.8 N.	.37108	.22279
			1915	0 11.7 W.	30 52.2 N.	.37166	.22217
			1920	0 20.7 W.	30 46.4 N.	.37174	.22137
			1925	0 30.2 W.	30 41.0 N.	.37220	.22085
			1926	0 32.6 W.	30 41.6 N.	.37218	.22092
			1927	0 34.7 W.	30 39.1 N.	.37271	.22085
			1928	0 33.3 W.	30 36.3 N.	.37219	.22016

v, w Because of electric car disturbances, superseded in January, 1913, by Kakioka and in 1908 by Lukiapang, respectively. x New constants determined in 1914, used thereafter, gave for that year smaller values in *H* by 31γ and in *Z* by 31γ than those based on the constants previously used. y Observations discontinued Apr. 26, 1915. z New site of Hong Kong observatory. Corrections to reduce Au Tau values to the Hong Kong series from 1884 are +9′.8 in *D* (i.e., west *D* is numerically less), −2′.5 in *I*, −159γ in *H*, −191γ in *Z*. aa Means, 10 months, March to December. bb Original observing hut replaced in 1921; values from 1925 reduced to basis of original hut; superseded by Au Tau in 1927.

MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Honolulu[cc]	21 19 N.	158 04 W.	1902	9 19.1 E.	40 14.5 N.	.29255	.24758
			1905	9 21.7 E.	40 05.8 N.	.29197	.24583
			1910	9 29.7 E.	39 47.2 N.	.29132	.24259
			1915	9 41.6 E.	39 20.1 N.	.29005	.23897
			1920	9 53.2 E.	39 25.1 N.	.28847	.23711
			1925	10 01.9 E.	39 25.4 N.	.28714	.23606
			1930	(10 04.4 E.)	(39 29.2 N.)	(.28542)	(.23516)
			1931	(10 04.3 E.)	(39 24.4 N.)	(.28551)	(.23458)
			1932	(10 05.0 E.)	(39 21.0 N.)	(.28545)	(.23405)
Teoloyucan	19 45 N.	99 11 W.	1919[b]	9 04.6 E.	....	......	......
			1925	9 14.7 E.	....	......	......
			1926	9 18.1 E.	....	......	......
			1928	9 22.2 E.	46 43.4 N.[b]	.31339[b]	......
			1930	9 25.4 E.	46 54.2 N.	.31190	.33343
			1931	(9 27.2 E.)[b]	(46 57.7 N.)[b]	(.31162)[b]	(.33375)[b]
Toungoo[dd]	18 56 N.	96 27 E.	1905	0 48.4 E.	22 58.3 N.	.38675	.16394
			1910	0 24.0 E.	23 02.1 N.	.38801	.16498
			1915	0 03.1 W.	23 07.2 N.	.39005[ee]	.16653[ee]
			1920	0 23.7 W.	23 07.7 N.	.39114	.16707
			1921	0 26.8 W.	23 07.0 N.	.39132	.16704
			1922	0 29.7 W.	23 07.2 N.	.39156	.16717
			1923[ff]	0 31.9 W.	23 06.1 N.	.39207	.16725
Colaba[gg] (Bombay)	18 54 N.	72 49 E.	1900	0 24.5 E.	21 22.4 N.	.37438	.14652
			1905	0 14.0 E.	21 58.5 N.	.37377	.15083
Alibag	18 38 N.	72 52 E.	1904	1 09.4 E.	22 54.7 N.	.36882	.15588
			1905	1 06.5 E.	23 01.6 N.	.36872	.15671
			1910	0 57.7 E.	23 39.6 N.[hh]	.36845	.16143[hh]
			1915	0 40.6 E.	24 21.1 N.	.36870	.16688
			1920	0 20.2 E.	24 54.7 N.	.36922	.17147
			1925	0 03.4 E.	25 18.5 N.	.37065[ii]	.17527[ii]
			1930	0 08.0 W.	25 30.6 N.	.37253	.17777
			1931	(0 10.5 W.)	(25 30.3 N.)	(.37323)	(.17806)
San Juan[jj]	18 23 N.	66 07 W.	1927[kk]	4 21.0 W.	52 10.6 N.	.27743	.35737
			1928	(4 35.6 W.)	(52 20.6 N.)	(.27644)	(.35824)
			1929	(4 41.9 W.)	(52 24.8 N.)	(.27551)	(.35795)
			1930	(4 50.5 W.)	(52 29.2 N.)	(.27403)	(.35813)
			1931	(4 58.8 W.)	(52 30.2 N.)	(.27451)	(.35780)
Vieques[ll]	18 09 N.	65 27 W.	1903[ll]	1 23.2 W.	49 10.0 N.	.29336	.33946
			1905	1 38.3 W.	49 17.0 N.	.29221	.33952
			1910	2 20.6 W.	49 52.0 N.	.28834	.34202
			1915	3 10.1 W.	50 45.9 N.	.28279	.34630
			1920	3 46.1 W.	51 22.7 N.	.27827	.34832
			1923	4 08.3 W.	51 37.8 N.	.27632	.34900
			1924[ll]	4 15.0 W.	51 41.8 N.	.27571	.34907
Antipolo	14 36 N.	121 10 E.	1911	0 41.3 E.	16 18.6 N.	.38072	.11140
			1915	0 37.3 E.	16 11.2 N.	.38095	.11057
			1920	0 35.9 E.	16 11.7 N.	.38100	.11065
			1925	0 29.8 E.	15 57.4 N.	.38211	.10925
			1930	(0 26.7 E.)[b]	(15 47.2 N.)[b]	(.38244)[b]	(.10812)[b]
			1931	(0 27.3 E.)[b]	(15 48.2 N.)[b]	(.38270)[b]	(.10832)[b]
Manila[mm]	14 35 N.	120 59 E.	1900	0 52.1 E.	16 15.9 N.	.38029	.11095
			1904	0 51.4 E.	16 00.2 N.	.38215	.10960
Kodaikanal[dd]	10 14 N.	77 28 E.	1903	0 23.4 W.	3 05 N.	.37367	.02013
			1905	0 31.9 W.	3 16.7 N.	.37403	.02142
			1910	0 55.0 W.	3 45.2 N.	.37485	.02459
			1915	1 22.3 W.	4 17.0 N.	.37614[nn]	.02817[nn]
			1920	1 49.9 W.	4 36.1 N.	.37787	.03042
			1921	1 54.2 W.	4 38.5 N.	.37832	.03071
			1922	1 58.7 W.	4 40.1 N.	.37878	.03093
			1923[ff]	2 00.7 W.	4 41.3 N.	.37950	.03112

[cc] 1913, change of earth inductors; the values with the inductor used previously appear to be 3′.0 too high. [dd] Discontinued 1923. [ee] New constants determined in 1914, used thereafter, gave for that year smaller values in H by 18γ and in Z by 7γ than those based on the constants previously used. [ff] Means, 9 months, January to September. [gg] Superseded by Alibag in 1906. [hh] In 1909 an earth inductor replaced the Kew dip-circle; observations of 1909–11 appear to show that the old values of I are about 2′ and of Z about 30γ too low. [ii] New 1923 constants make a change of -21γ and -10γ, respectively, necessary for values of H and Z given from 1904–22. [jj] Superseding Vieques Observatory. [kk] Five months means, January to May. [ll] Discontinued October 31, 1924; values for 1903, means for 9 months, April to December and those for 1924, 10 months, January to October. [mm] Superseded by Antipolo because of electric car disturbances. [nn] 1914, new constants, thereafter used, gave for that year larger values in H by 33γ and in Z by 3γ.

MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES

Observatory	Latitude	Longitude	Year	Declination (*D*)	Inclination (*I*)	Intensity Hor. (*H*)	Intensity Ver. (*Z*)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Palau[b]	7 20 N.	134 29 E.	1926	2 00.5 E.	....	......	......
			1927	2 00.2 E.	....	......	......
			1928	1 59.9 E.	....	......	......
			1929	1 59.8 E.	....	......	......
Batavia-	6 11 S.	106 49 E.	1902[oo]	1 02.4 E.	30 17.6 S.	.36717	−.21450
Buitenzorg			1905	0 55.0 E.	30 39.7 S.	.36690	−.21752
			1910	0 48.7 E.	31 12.0 S.	.36660	−.22202
			1915	0 46.1 E.	31 33.6 S.	.36676	−.22528
			1920	0 47.0 E.	31 53.7 S.	.36796	−.22899
			1925	0 53.2 E.	32 06.0 S.	.36819	−.23097
			1926	0 51.6 E.	32 09.6 S.	.36826	−.23154
			1927[b]	0 52.5 E.	32 10.5 S.	.36853	−.23185
			1928	0 53.0 E.	32 14.9 S.	.36834	−.23239
Huancayo	12 03 S.	75 20 W.	1925[b]	7 59.1 E.	1 01.5 N.	.29750	.00532
			1926[b]	7 55.5 E.	1 09.8 N.	.29725	.00604
			1927[b]	7 50.7 E.	1 17.3 N.	.29737	.00669
			1928[b]	7 47.2 E.	1 25.8 N.	.29667	.00741
			1929[b]	7 42.3 E.	1 33.9 N.	.29675	.00811
			1930	7 36.5 E.	1 42.7 N.	.29614	.00885
Apia	13 48 S.	171 46 W.	1905	9 37.0 E.	29 11.8 S.	.35675	−.19935
(Samoa)			1910	9 45.6 E.	29 29.8 S.	.35550	−.20110
			1915	9 57.0 E.	29 52.8 S.	.35386	−.20331
			1920	10 11.2 E.	30 03.5 S.	.35273	−.20413
			1925	10 22.8 E.	30 07.9 S.	.35239	−.20453
			1926	10 26.2 E.	30 08.0 S.	.35228	−.20449
			1927	10 29.5 E.	(30 07.0 S.)	.35223	......
			1928	10 32.1 E.	....	.35225	−.20408
			1929	10 33.5 E.	....	.35209	−.20418
			1930	10 34.2 E.	30 07.9 S.	.35196	−.20428
			1931	10 35.2 E.	30 09.3 S.[b]	.35171	−.20434
Tananarive*[b]	18 55 S.	47 32 E.	1902[pp]	10 15.0 W.	54 06.8 S.	.23168	−.32021
			1903	10 07.0 W.	54 06.5 S.	.23113	−.31939
			1905	9 47.9 W.	54 07.6 S.	.22940	−.31721
			1910	9 01.3 W.	53 58.9 S.	.22585	−.31065
			1915	8 19.2 W.	53 34.4 S.	.22417	−.30376
			1916	8 14.0 W.	53 32.8 S.	.22366	−.30277
			1917	8 09.1 W.	53 29.8 S.	.22306	−.30141
			1918	8 04.2 W.	53 23.6 S.	.22260	−.29966
			1919	8 04.6 W.	53 21.2 S.	.22218	−.29866
Mauritius	20 06 S.	57 33 E.	1900	9 29.0 W.	54 11.0 S.	.23826	−.33015
			1905	9 11.3 W.	53 55.5 S.	.23584	−.32371
			1910	9 18.1 W.	53 34.7 S.	.23327	−.31615
			1915	9 41.1 W.[qq]	53 00.2 S.[qq]	.23226	−.30833[qq]
			1920	10 20.3 W.	52 40.1 S.	.23093	−.30278
			1925	11 09.6 W.	52 31.0 S.	.22906	−.29867
			1926	11 19.8 W.	52 33.6 S.	.22852	−.29849
			1927	11 32.0 W.	52 28.8 S.[rr](?)	.22804	−.29701[rr](?)
			1928	11 42.7 W.	52 44.6 S.	.22768	−.29934
			1929	11 53.9 W.	52 45.0 S.	.22732	−.29893
			1930	12 05.5 W.	52 39.6 S.	.22697	−.29750
			1931	(12 17.2 W.)	(52 38.3 S.)	(.22673)	(−.29696)
La Quiaca[b]	22 07 S.	65 35 W.	1920	6 03.3 E.	12 39.6 S.	.26621	−.05979
			1925	5 29.1 E.	12 28.2 S.	.26435	−.05848
			1930	4 40.7 E.	12 23.8 S.	.26266	−.05774
			1931	4 31.7 E.	12 22.8 S.	.26256	−.05763
Vassouras	22 24 S.	43 39 W.	1915	10 28.1 W.	14 44.1 S.	.24700	−.06496
			1920	11 17.7 W.	15 21.6 S.	.24494	−.06728
			1925	12 03.5 W.	16 15.6 S.	.24333[ss]	−.07007
			1926	12 10.5 W.	16 31.2 S.	.24293	−.07205
			1927	12 19.6 W.	16 39.7 S.	.24276	−.07265
			1928	12 28.7 W.	16 47.4 S.	.24221[tt]	−.07308
Rio de	22 55 S.	43 11 W.	1900	7 55.7 W.	13 17.1 S.	.2504	−.0592
Janeiro[uu]			1905	8 46.6 W.	13 51.7 S.	.24777	−.06098
			1910	9 40.0 W.	....	......	......

[oo] Means, 6 months, July to December. [pp] Means, 8 months, May to December. [qq] The *D* values from 1912 to be decreased by 5′.1 for comparison with values in previous years; in 1914 an earth inductor replaced the dip circle on another pier and values are referred to dip-circle pier. [rr] Trouble experienced with galvanometer; earth inductor replaced by dip circle in 1928; the values of *I* and *Z* for 1927 are indicated as only approximate. [ss] No data in June, and only 4 days in May and 7 days in July. [tt] No data in January. [uu] Superseded about 1913 by Vassouras.

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Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Watheroo	30 19 S.	115 52 E.	1919	4 22.8 W.	63 51.4 S.	.24925	−.50780
			1920	4 22.1 W.	63 54.7 S.	.24889	−.50832
			1925	4 17.6 W.	64 07.8 S.	.24719	−.50977
			1926	4 17.2 W.	64 10.7 S.	.24681	−.51007
			1927	4 16.3 W.	64 11.8 S.	.24671	−.51030
			1928	4 15.0 W.	64 13.8 S.	.24656	−.51070
			1929	4 12.1 W.	64 15.5 S.	.24646	−.51116
			1930	4 08.0 W.	64 17.7 S.	.24634	−.51174
			1931	4 03.2 W.	64 18.1 S.	.24646	−.51215
Pilar	31 40 S.	63 53 W.	1905	9 51.7 E.	26 03.0 S.	.25894	−.12657
			1910	9 13.9 E.	25 52.8 S.	.25694	−.12465
			1914	8 40.4 E.	25 41.5 S.	.25597	−.12315
			1916	8 22.9 E.	25 40.9 S.	.25495	−.12260
			1920	7 48.6 E.	25 41.2 S.	.25297	−.12168
			1925	7 06.2 E.	25 41.3 S.	.25012	−.12031
			1930	6 26.8 E.	25 50.6 S.	.24695	−.11961
			1931	6 18.9 E.	25 51.2 S.	.24661	−.11950
Santiago[b]	33 27 S.	70 42 W.	1902	14 41.6 E.	30 55.8 S.	......	......
			1905	14 27.0 E.	30 25.0 S.	......	......
			1909	13 57.9 E.	29 57.2 S.	......	......
Melbourne[b,vv]	37 50 S.	144 58 E.	1916	8 06.7 E.	67 48.9 S.	.22998	−.56397
			1919	8 01.0 E.	67 53.8 S.	.22895	−.56374
Toolangi	37 32 S.	145 28 E.	1920[b]	8 00.8 E.	67 55.1 S.	.22874	−.56384
			1925	8 10.4 E.	67 44.5 S.	.22948	−.56071
			1930[b]	8 21.6 E.	67 52.4 S.	.22851	−.56198
			1931[b]	(8 24.5 E.	(67 51.1 S.)	(.22890)	(−.56232)
Amberley	43 10 S.	172 44 E.	1929	17 45.0 E.	67 57.8 S.	.22365	.55252
			1930	17 51.0 E.	67 58.4 S.	.22351	.55246
Christchurch[ww]	43 32 S.	172 37 E.	1902	16 15.1 E.	67 40.8 S.	.22694	−.55277
			1905	16 25.4 E.	67 45.8 S.	.22628	−.55348
			1910	16 37.6 E.	67 54.8 S.	.22515	−.55485
			1914	16 44.8 E.	67 59.8 S.	.22414	−.55465
			1917	16 53.0 E.	68 04.8 S.	.22328	−.55486
			1920	17 01.7 E.	68 09.2 S.	.22261	−.55525
			1925	17 21.1 E.	68 14.2 S.	.22166	−.55522
			1930	17 48.3 E.	68 18.3 S.	.22108	−.55570
New Year's Island	54 39 S.	64 09 W.	1902[xx]	15 57.3 E.	50 13.8 S.	.27306	−.32808
			1905	15 45.7 E.	50 06.6 S.	.27196	−.32536
			1910	15 26.3 E.	....	.27040	−.32114[xx]
			1915	15 06.6 E.	49 41.6 S.	.26821	−.31619
			1916	15 02.4 E.	49 39.4 S.	.26771	−.31520
Orcadas	60 43 S.	44 47 W.	1905	5 16.6 E.[yy]	54 31.0 S.[yy,b]	.25667[zz]	......
			1909	4 56.6 E.	54 27.4 S.[b]	.25436	......
			1912	4 46.5 E.	54 26.0 S.[b]	.25343	−.35442[b]

[vv] Superseded in 1920 by Toolangi. [ww] January 1, 1923, the variation observatory was transferred to Amberly but all results subsequently are referred to basis of the old station at Christchurch. [xx] Means, 10 months, March to December in 1902 for all elements, and 9 months, January to September in 1910 for Z. [yy] Mean, 11 months, February to December. [zz] Mean, 10 months, March to December.

TABLE 738.—Bibliography

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Table 739

SECULAR CHANGE OF MAGNETIC DECLINATION

Changes in the magnetic declination between 1820, or the date of the earliest observations, and 1930, based on tables in "Magnetic Declination in the United States in 1925" published by the U. S. Coast and Geodetic Survey (Special Publication No. 126) in 1926.

State	Lat.	Long.	1820	1830	1840	1850	1860	1870	1880	1890	1900	1910	1920	1930
	°	°	°	°	°	°	°	°	°	°	°	°	°	°
At sea	44	68	12.2W	13.0W	13.8W	14.6W	15.4W	15.8W	16.2W	16.5W	16.8W	17.5W	18.3W	19.1W
Me.	46	68	14.8W	15.6W	16.4W	17.3W	18.0W	18.5W	18.9W	19.0W	19.3W	20.0W	20.7W	21.3W
Canada	48	68	17.6W	18.5W	19.4W	20.2W	21.0W	21.5W	21.8W	21.9W	22.1W	22.7W	23.2W	23.8W
At sea	40	72	5.0W	5.5W	6.2W	6.9W	7.6W	8.2W	8.7W	9.2W	9.7W	10.6W	11.3W	12.2W
Conn.	42	72	6.5W	7.0W	7.7W	8.4W	9.1W	9.7W	10.3W	10.8W	11.3W	12.1W	12.9W	13.7W
N. H.	44	72	8.3W	8.9W	9.6W	10.4W	11.1W	11.7W	12.3W	12.7W	13.2W	14.0W	14.8W	15.7W
Canada	46	72	10.9W	11.5W	12.2W	13.0W	13.7W	14.3W	15.0W	15.3W	15.8W	16.6W	17.3W	18.0W
At sea	34	76	1.2E	0.9E	0.4E	0.2W	0.8W	1.4W	2.0W	2.6W	3.1W	3.7W	4.2W	4.6W
N. C.	36	76	0.2E	0.2W	0.6W	1.2W	1.8W	2.5W	3.1W	3.6W	4.2W	4.8W	5.4W	5.9W
Md.	38	76	0.4W	0.8W	1.3W	1.9W	2.5W	3.2W	3.8W	4.4W	5.0W	5.6W	6.3W	6.9W
Pa.	40	76	1.6W	2.0W	2.5W	3.1W	3.7W	4.4W	5.0W	5.6W	6.2W	7.0W	7.6W	8.4W
Pa.	42	76	3.4W	3.8W	4.3W	4.9W	5.5W	6.2W	7.0W	7.5W	8.1W	8.9W	9.6W	10.4W
N. Y.	44	76	4.7W	5.1W	5.7W	6.3W	7.0W	7.6W	8.5W	9.0W	9.6W	10.4W	11.2W	12.0W
At sea	26	80	5.4E	5.1E	4.7E	4.2E	3.7E	3.1E	2.6E	2.0E	1.5E	1.3E	1.4E	1.5E
At sea	28	80	4.9E	4.6E	4.3E	3.8E	3.3E	2.7E	2.1E	1.5E	1.0E	0.8E	0.7E	0.8E
At sea	30	80	4.6E	4.3E	3.9E	3.5E	2.9E	2.3E	1.7E	1.1E	0.6E	0.3E	0.2E	0.1E
At sea	32	80	4.0E	3.8E	3.4E	3.0E	2.4E	1.8E	1.2E	0.6E	0.0	0.3W	0.5W	0.7W
S. C.	34	80	3.7E	3.4E	3.1E	2.6E	2.0E	1.4E	0.8E	0.2E	0.4W	0.8W	1.1W	1.4W
N. C.	36	80	2.6E	2.4E	2.0E	1.5E	1.0E	0.3E	0.4W	1.0W	1.5W	2.0W	2.4W	2.8W
Va.	38	80	2.0E	1.8E	1.4E	0.9E	0.3E	0.3W	1.0W	1.6W	2.2W	2.7W	3.2W	3.7W
Pa.	40	80	0.9E	0.7E	0.3E	0.2W	0.8W	1.4W	2.1W	2.8W	3.4W	4.0W	4.5W	5.1W
Pa.	42	80	0.6E	0.4E	0.0	0.5W	1.1W	1.8W	2.5W	3.2W	3.8W	4.4W	5.1W	5.8W
Canada	44	80	0.8W	1.1W	1.5W	2.0W	2.6W	3.3W	4.1W	4.8W	5.4W	6.1W	6.8W	7.6W
Fla.	30	84	6.2E	6.1E	5.9E	5.5E	5.0E	4.5E	3.9E	3.2E	2.8E	2.7E	2.8E	2.9E
Ga.	32	84	5.7E	5.6E	5.3E	5.0E	4.5E	3.9E	3.3E	2.6E	2.1E	2.0E	2.0E	2.0E
Ga.	34	84	5.3E	5.2E	4.9E	4.5E	4.0E	3.4E	2.8E	2.1E	1.6E	1.4E	1.3E	1.2E
Tenn.	36	84	4.0E	3.9E	3.6E	3.2E	2.7E	2.1E	1.4E	0.8E	0.2E	0.0	0.2W	0.5W
Ky.	38	84	4.7E	4.6E	4.3E	3.9E	3.4E	2.8E	2.1E	1.4E	0.9E	0.6E	0.3E	0.1W
Ohio	40	84	4.3E	4.2E	3.8E	3.4E	2.9E	2.4E	1.7E	1.0E	0.4E	0.0	0.4W	0.9W
Mich.	42	84	3.1E	2.9E	2.6E	2.2E	1.7E	1.1E	0.4E	0.4W	1.0W	1.4W	1.8W	2.5W
Mich.	44	84	2.8E	2.6E	2.3E	1.9E	1.4E	0.8E	0.0	0.8W	1.4W	1.8W	2.4W	3.1W
Mich.	46	84	1.5E	1.4E	1.0E	0.6E	0.1E	0.5W	1.3W	2.1W	2.7W	3.2W	3.8W	4.7W
Ala.	30	88	7.3E	7.3E	7.2E	7.0E	6.6E	6.1E	5.6E	4.9E	4.5E	4.6E	4.9E	5.1E
Ala.	32	88	7.1E	7.1E	7.0E	6.7E	6.4E	5.9E	5.3E	4.6E	4.2E	4.2E	4.4E	4.5E
Ala.	34	88	7.4E	7.4E	7.2E	7.0E	6.6E	6.1E	5.5E	4.8E	4.3E	4.3E	4.4E	4.4E
Tenn.	36	88	7.2E	7.2E	7.1E	6.8E	6.4E	5.9E	5.2E	4.6E	4.1E	4.0E	4.0E	3.8E
Ind.	38	88	7.2E	7.2E	7.0E	6.7E	6.3E	5.8E	5.1E	4.4E	3.9E	3.8E	3.7E	3.3E
Ill.	40	88	6.9E	6.9E	6.7E	6.4E	6.0E	5.5E	4.8E	4.1E	3.6E	3.4E	3.2E	2.7E
Ill.	42	88	6.5E	6.5E	6.4E	6.0E	5.6E	5.1E	4.4E	3.7E	3.1E	2.9E	2.6E	1.9E
Wis.	44	88	6.3E	6.3E	6.2E	5.8E	5.4E	4.9E	4.2E	3.4E	2.8E	2.5E	2.1E	1.4E
Mich.	46	88	5.9E	6.0E	5.8E	5.5E	5.0E	4.5E	3.7E	3.0E	2.4E	2.1E	1.6E	0.7E
Lake	48	88	5.6E	5.7E	5.5E	5.2E	4.8E	4.2E	3.4E	2.6E	2.0E	1.7E	1.1E	0.2E
La.	30	92	8.3E	8.5E	8.5E	8.4E	8.1E	7.8E	7.2E	6.7E	6.3E	6.6E	7.0E	7.2E
La.	32	92	8.5E	8.7E	8.6E	8.5E	8.3E	7.9E	7.4E	6.8E	6.4E	6.6E	6.9E	7.1E
Ark.	34	92	8.8E	8.9E	8.9E	8.8E	8.5E	8.1E	7.6E	7.0E	6.6E	6.7E	6.9E	6.9E
Ark.	36	92	8.8E	8.9E	8.9E	8.7E	8.4E	8.0E	7.5E	6.8E	6.4E	6.5E	6.7E	6.5E
Mo.	38	92	9.0E	9.2E	9.1E	9.0E	8.6E	8.2E	7.7E	7.0E	6.5E	6.6E	6.6E	6.4E
Mo.	40	92	9.2E	9.4E	9.3E	9.1E	8.8E	8.4E	7.8E	7.1E	6.6E	6.6E	6.5E	6.1E
Iowa	42	92	9.5E	9.7E	9.7E	9.5E	9.2E	8.7E	8.1E	7.4E	6.9E	6.8E	6.6E	6.0E
Minn.	44	92	9.2E	9.3E	9.3E	9.1E	8.8E	8.4E	7.7E	7.0E	6.4E	6.4E	6.1E	5.4E
Minn.	46	92	9.1E	9.2E	9.2E	9.0E	8.7E	8.3E	7.6E	6.8E	6.3E	6.3E	5.9E	5.1E
Minn.	48	92	8.7E	8.9E	8.9E	8.7E	8.4E	8.0E	7.2E	6.5E	5.9E	5.9E	5.5E	4.5E
At sea	28	96	8.5E	8.8E	8.9E	8.9E	8.8E	8.6E	8.2E	7.8E	7.6E	8.0E	8.5E	8.8E
Tex.	30	96	9.0E	9.2E	9.3E	9.3E	9.2E	9.0E	8.6E	8.1E	7.9E	8.3E	8.7E	8.9E
Tex.	32	96	9.2E	9.4E	9.6E	9.6E	9.4E	9.2E	8.8E	8.2E	8.0E	8.3E	8.7E	8.8E
Okla.	34	96	9.6E	9.8E	9.9E	9.9E	9.8E	9.5E	9.1E	8.6E	8.2E	8.5E	8.8E	8.8E
Okla.	36	96	10.2E	10.4E	10.5E	10.5E	10.4E	10.1E	9.7E	9.1E	8.8E	9.0E	9.2E	9.1E
Kans.	38	96	11.1E	11.3E	11.4E	11.4E	11.2E	11.0E	10.5E	9.9E	9.5E	9.8E	9.9E	9.6E
Kans.	40	96	11.2E	11.4E	11.5E	11.5E	11.3E	11.0E	10.5E	9.9E	9.5E	9.7E	9.7E	9.3E
Iowa	42	96	11.5E	11.7E	11.8E	11.8E	11.6E	11.3E	10.8E	10.1E	9.7E	9.8E	9.8E	9.2E
Minn.	44	96	11.6E	11.9E	12.0E	12.0E	11.8E	11.4E	10.9E	10.2E	9.8E	9.9E	9.7E	9.1E
Minn.	46	96	12.4E	12.7E	12.8E	12.7E	12.5E	12.2E	11.6E	10.9E	10.5E	10.6E	10.4E	9.6E
Minn.	48	96	12.4E	12.7E	12.8E	12.7E	12.5E	12.2E	11.6E	10.8E	10.4E	10.5E	10.2E	9.3E

Table 739 (continued)

SECULAR CHANGE OF MAGNETIC DECLINATION

State	Lat.	Long.	1820	1830	1840	1850	1860	1870	1880	1890	1900	1910	1920	1930
	°	°	°	°	°	°	°	°	°	°	°	°	°	°
Mexico	28	100	.....	9.6E	9.8E	9.9E	9.9E	9.8E	9.5E	9.1E	9.0E	9.5E	10.0E	10.3E
Tex.	30	100	.....	9.9E	10.1E	10.2E	10.2E	10.1E	9.8E	9.3E	9.2E	9.7E	10.2E	10.4E
Tex.	32	100	.....	10.6E	10.8E	10.8E	10.8E	10.7E	10.4E	9.9E	9.8E	10.2E	10.6E	10.7E
Tex.	34	100	.....	11.0E	11.2E	11.2E	11.2E	11.1E	10.8E	10.3E	10.1E	10.5E	10.8E	10.8E
Okla.	36	100	.....	11.7E	11.9E	12.0E	11.9E	11.8E	11.4E	11.0E	10.8E	11.1E	11.4E	11.3E
Kans.	38	100	.....	12.2E	12.4E	12.4E	12.4E	12.2E	11.8E	11.3E	11.1E	11.4E	11.6E	11.4E
Kans.	40	100	.....	12.8E	13.0E	13.0E	13.0E	12.8E	12.4E	11.8E	11.6E	11.9E	12.0E	11.6E
Nebr.	42	100	.....	13.1E	13.3E	13.3E	13.2E	13.1E	12.6E	12.1E	11.8E	12.0E	12.1E	11.6E
S. Dak.	44	100	.....	14.2E	14.4E	14.4E	14.3E	14.1E	13.7E	13.0E	12.8E	13.0E	13.0E	12.4E
N. Dak.	46	100	.....	15.0E	15.2E	15.3E	15.2E	15.0E	14.5E	13.9E	13.5E	13.8E	13.7E	13.0E
N. Dak.	48	100	.....	15.6E	15.8E	15.8E	15.8E	15.5E	15.0E	14.4E	14.0E	14.3E	14.1E	13.3E
Tex.	30	104	.....	10.6E	10.8E	11.0E	11.1E	11.1E	10.9E	10.5E	10.5E	11.0E	11.5E	11.7E
Tex.	32	104	.....	11.3E	11.6E	11.7E	11.8E	11.8E	11.6E	11.2E	11.1E	11.6E	12.0E	12.1E
N. Mex.	34	104	.....	12.0E	12.2E	12.4E	12.5E	12.5E	12.2E	11.8E	11.7E	12.2E	12.6E	12.6E
N. Mex.	36	104	.....	.....	.....	13.1E	13.2E	13.2E	13.0E	12.5E	12.4E	12.9E	13.2E	13.1E
Colo.	38	104	.....	.....	.....	13.7E	13.8E	13.8E	13.5E	13.0E	12.9E	13.4E	13.6E	13.4E
Colo.	40	104	.....	.....	.....	14.4E	14.5E	14.5E	14.2E	13.7E	13.6E	14.0E	14.2E	13.8E
Nebr.	42	104	.....	.....	.....	15.6E	15.7E	15.7E	15.4E	14.8E	14.7E	15.1E	15.2E	14.8E
S. Dak.	44	104	.....	.....	.....	16.4E	16.4E	16.3E	16.0E	15.5E	15.4E	15.8E	15.8E	15.3E
N. Dak.	46	104	.....	.....	.....	17.3E	17.3E	17.2E	16.9E	16.3E	16.2E	16.6E	16.5E	15.9E
N. Dak.	48	104	.....	.....	.....	18.5E	18.6E	18.4E	18.0E	17.5E	17.3E	17.7E	17.5E	16.8E
Mexico	30	108	.....	.....	.....	11.5E	11.7E	11.8E	11.7E	11.4E	11.4E	12.1E	12.5E	12.6E
N. Mex.	32	108	.....	.....	.....	12.3E	12.5E	12.6E	12.5E	12.2E	12.2E	12.8E	13.2E	13.2E
N. Mex.	34	108	.....	.....	.....	13.0E	13.2E	13.3E	13.1E	12.8E	12.8E	13.4E	13.8E	13.7E
N. Mex.	36	108	.....	.....	.....	13.7E	13.9E	14.0E	13.8E	13.5E	13.5E	14.1E	14.4E	14.3E
Colo.	38	108	.....	.....	.....	14.5E	14.7E	14.8E	14.6E	14.2E	14.2E	14.8E	15.0E	14.8E
Colo.	40	108	.....	.....	.....	15.5E	15.7E	15.8E	15.6E	15.2E	15.2E	15.7E	15.9E	15.6E
Wyo.	42	108	.....	.....	.....	16.4E	16.6E	16.7E	16.4E	16.1E	16.1E	16.6E	16.7E	16.3E
Wyo.	44	108	.....	.....	.....	17.6E	17.8E	17.8E	17.6E	17.2E	17.2E	17.7E	17.7E	17.3E
Mont.	46	108	.....	.....	.....	18.7E	18.9E	19.0E	18.7E	18.3E	18.3E	18.8E	18.8E	18.2E
Mont.	48	108	.....	.....	.....	20.2E	20.4E	20.4E	20.1E	19.7E	19.7E	20.2E	20.1E	19.4E
Ariz.	32	112	.....	.....	.....	12.6E	12.9E	13.1E	13.1E	12.9E	13.0E	13.8E	14.2E	14.2E
Ariz.	34	112	.....	.....	.....	13.3E	13.6E	13.8E	13.7E	13.6E	13.6E	14.4E	14.7E	14.6E
Ariz.	36	112	.....	.....	.....	14.1E	14.4E	14.6E	14.5E	14.3E	14.4E	15.1E	15.4E	15.3E
Utah	38	112	.....	.....	.....	15.2E	15.4E	15.6E	15.6E	15.4E	15.4E	16.1E	16.3E	16.2E
Utah	40	112	.....	.....	.....	16.3E	16.6E	16.8E	16.7E	16.5E	16.6E	17.2E	17.4E	17.1E
Utah	42	112	.....	.....	.....	17.4E	17.7E	17.9E	17.8E	17.6E	17.7E	18.2E	18.4E	18.1E
Idaho	44	112	.....	.....	.....	18.5E	18.8E	19.0E	18.8E	18.6E	18.7E	19.3E	19.4E	19.0E
Mont.	46	112	.....	.....	.....	19.4E	19.8E	19.9E	19.8E	19.5E	19.6E	20.2E	20.2E	19.8E
Mont.	48	112	.....	.....	.....	21.0E	21.3E	21.5E	21.3E	21.0E	21.1E	21.7E	21.7E	21.2E
Mexico	32	116	11.4E	11.8E	12.3E	12.6E	13.0E	13.3E	13.4E	13.4E	13.6E	14.4E	14.8E	14.7E
Calif.	34	116	12.3E	12.8E	13.2E	13.5E	13.9E	14.2E	14.3E	14.2E	14.4E	15.2E	15.6E	15.5E
Calif.	36	116	13.1E	13.6E	14.0E	14.4E	14.8E	15.1E	15.1E	15.1E	15.3E	16.0E	16.3E	16.2E
Nev.	38	116	.....	.....	15.0E	15.4E	15.8E	16.1E	16.1E	16.1E	16.3E	17.0E	17.2E	17.1E
Nev.	40	116	.....	.....	15.9E	16.2E	16.6E	16.9E	17.0E	16.9E	17.1E	17.8E	18.0E	17.8E
Nev.	42	116	.....	.....	17.2E	17.5E	17.9E	18.2E	18.2E	18.2E	18.4E	19.0E	19.2E	19.0E
Idaho	44	116	.....	.....	18.2E	18.6E	19.0E	19.3E	19.3E	19.2E	19.4E	20.1E	20.2E	19.9E
Idaho	46	116	.....	.....	19.9E	20.3E	20.7E	21.0E	21.0E	20.9E	21.2E	21.8E	21.9E	21.5E
Mont.	48	116	.....	.....	21.1E	21.5E	21.9E	22.2E	22.2E	22.2E	22.4E	23.0E	23.1E	22.6E
At sea	34	120	12.5E	12.8E	13.1E	13.5E	14.0E	14.4E	14.6E	14.6E	14.9E	15.8E	16.1E	16.0E
Calif.	36	120	13.5E	13.8E	14.2E	14.6E	15.0E	15.4E	15.6E	15.6E	15.9E	16.8E	17.1E	16.9E
Calif.	38	120	14.2E	14.5E	14.9E	15.3E	15.8E	16.2E	16.4E	16.4E	16.7E	17.5E	17.8E	17.6E
Calif.	40	120	15.3E	15.7E	16.0E	16.5E	17.0E	17.4E	17.5E	17.6E	17.8E	18.6E	18.8E	18.6E
Calif.	42	120	16.5E	17.0E	17.4E	17.8E	18.3E	18.7E	18.8E	18.9E	19.1E	19.9E	20.1E	19.9E
Oreg.	44	120	18.0E	18.5E	18.9E	19.4E	19.8E	20.2E	20.3E	20.4E	20.7E	21.5E	21.7E	21.4E
Wash.	46	120	18.9E	19.4E	19.9E	20.3E	20.8E	21.2E	21.3E	21.4E	21.7E	22.4E	22.6E	22.2E
Wash.	48	120	19.8E	20.5E	20.9E	21.4E	21.9E	22.3E	22.4E	22.5E	22.9E	23.6E	23.7E	23.3E
At sea	38	124	14.2E	14.6E	14.9E	15.4E	16.0E	16.5E	16.7E	16.8E	17.2E	18.0E	18.3E	18.2E
Calif.	40	124	15.3E	15.6E	16.0E	16.5E	17.1E	17.6E	17.8E	17.9E	18.3E	19.1E	19.4E	19.2E
Calif.	42	124	16.5E	16.9E	17.3E	17.8E	18.4E	18.8E	19.1E	19.2E	19.6E	20.4E	20.7E	20.5E
Oreg.	44	124	17.5E	18.0E	18.4E	18.9E	19.5E	20.0E	20.2E	20.4E	20.8E	21.6E	21.9E	21.6E
Oreg.	46	124	18.4E	19.0E	19.5E	20.0E	20.6E	21.1E	21.3E	21.5E	21.9E	22.8E	23.0E	22.7E
Wash.	48	124	19.5E	20.2E	20.6E	21.2E	21.8E	22.3E	22.5E	22.8E	23.2E	24.0E	24.2E	23.8E

TABLE 740.—Dip or Inclination, United States

This table gives for the epoch January 1, 1925, the values of the magnetic dip, *I*, corresponding to the longitudes west of Greenwich in the heading and the north latitudes in the first column.

φ \ λ	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	120°	125°
°	°	°	°	°	°	°	°	°	°	°	°	°	°
19	....	....	51.5	50.6	49.6	....	....	....	....	....	....	....	....
21	....	....	53.8	53.0	52.1	50.9	....	....	....	....	....	....	....
23	....	....	56.3	55.4	54.5	53.4	52.2	50.9	50.0	....	....	....	....
25	....	....	58.6	57.8	56.9	55.9	54.8	53.5	52.4	51.3	50.2	....	....
27	....	....	60.6	60.0	59.1	58.3	57.1	55.9	54.8	53.7	52.5	51.5	....
29	....	62.1	62.6	62.1	61.3	60.5	59.4	58.1	57.0	55.9	54.8	53.8	....
31	....	64.0	64.3	64.0	63.5	62.6	61.5	60.5	59.2	58.2	57.0	55.9	....
33	....	65.8	66.1	65.7	65.2	64.4	63.5	62.6	61.3	60.1	59.2	58.1	....
35	....	67.5	67.9	67.6	66.9	66.5	65.6	64.5	63.4	62.3	61.0	60.1	....
37	....	69.3	69.6	69.2	69.1	68.4	67.5	66.6	65.3	64.3	63.0	62.1	....
39	....	70.8	71.0	70.9	70.8	70.3	69.4	68.4	67.3	66.2	65.0	63.9	62.7
41	....	72.2	72.5	72.7	72.4	71.9	71.1	70.2	69.0	68.0	66.7	65.6	64.3
43	....	73.6	73.9	74.2	73.9	73.6	72.7	71.9	70.8	69.8	68.4	67.4	66.1
45	74.0	74.7	75.3	75.6	75.6	75.2	74.5	73.6	72.6	71.3	70.2	69.0	67.8
47	75.3	76.1	76.7	77.1	77.1	76.8	76.1	75.2	74.3	72.9	71.7	70.7	69.4
49	76.3	77.2	77.9	78.4	78.6	78.3	77.7	76.8	75.8	74.6	73.2	72.0	70.9

TABLE 741.—Secular Change of Dip, United States

Values of the magnetic dip for places designated by the north latitudes and longitudes west of Greenwich in the first two columns for January 1, of the years in the heading. The degrees are given in the third column and the minutes in the succeeding columns.

Latitude	Longitude		1855	1865	1875	1885	1895	1900	1905	1910	1915	1920	1925
°	°	°	′	′	′	′	′	′	′	′	′	′	′
25	80	55+	29	27	22	12	16	25	42	77	114	144	171
25	90	53+	17	23	34	40	34	44	73	106	136	157	177
25	100	51+	15	33	50	49	61	71	87	107	126	140	151
31	80	62+	45	43	37	22	18	23	35	57	81	101	120
31	90	60+	52	60	67	58	60	68	81	104	124	140	155
31	100	59+	01	15	26	22	28	36	48	62	74	83	91
31	110	57+	05	16	24	28	38	43	49	56	63	67	71
37	80	68+	60	55	49	31	20	21	27	39	53	65	75
37	90	67+	34	40	42	33	27	32	40	53	65	75	83
37	100	65+	45	54	61	55	56	61	70	79	86	91	95
37	110	63+	..	..	53	54	60	63	66	70	73	76	78
37	120	61+	52	54	57	61	69	67	64	64	63	65	66
43	70	73+	117	107	90	67	45	38	38	38	38	37	36
43	80	73+	106	100	92	73	55	52	54	59	65	68	70
43	90	73+	36	36	35	26	16	17	20	26	32	35	38
43	100	71+	..	..	48	41	37	39	43	47	50	53	55
43	110	69+	..	..	44	42	44	45	46	46	46	48	49
43	120	67+	..	..	26	29	33	29	26	24	22	22	22
47	70	76+	109	97	80	57	32	25	22	19	15	10	05
47	80	77+	66	60	50	31	11	07	06	06	07	06	04
49	90	78+	53	50	45	36	24	21	20	20	20	20	20
49	100	76+	..	..	62	55	49	48	47	46	45	45	46
49	110	74+	..	..	47	44	43	41	40	37	35	35	35
49	120	72+	..	..	18	19	19	15	11	06	02	01	00

TABLE 742.—Horizontal Magnetic Intensity, United States

This table gives for the epoch January 1, 1925, the horizontal intensity, H, expressed in c.g.s. units, corresponding to the longitudes in the heading and the latitudes in the first column.

λ / φ °	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	120°	125°
19	....	....	.286	.294	.302	.308	.315	.320	....	....	....	....	....
21	....	....	.280	.286	.294	.301	.307	.312	.313	.313	....	....	....
23	....	....	.272	.279	.285	.293	.300	.304	.305	.306	....	....	....
25	....	....	.263	.270	.276	.282	.290	.295	.297	.298	.298	....	....
27	....	....	.254	.260	.267	.273	.280	.286	.289	.291	.292	.292	....
29	....	.240	.244	.249	.257	.264	.270	.276	.280	.283	.284	.285	....
31	....	.230	.234	.238	.245	.253	.260	.266	.271	.274	.276	.277	....
33	....	.220	.223	.227	.234	.241	.248	.254	.260	.264	.268	.268	....
35	....	.209	.211	.215	.223	.228	.235	.242	.247	.252	.256	.258	....
37	....	.197	.198	.202	.208	.214	.222	.227	.235	.240	.245	.249	....
39	....	.186	.187	.190	.193	.200	.207	.215	.223	.228	.235	.239	.242
41	....	.174	.175	.176	.182	.187	.193	.202	.209	.216	.223	.228	.232
43	.165	.163	.162	.163	.167	.171	.178	.187	.195	.203	.211	.217	.222
45	.155	.153	.151	.150	.152	.157	.163	.172	.181	.190	.198	.205	.212
47	.145	.142	.138	.136	.138	.139	.148	.157	.165	.176	.185	.192	.201
49	.135	.130	.126	.123	.123	.126	.134	.142	.152	.160	.171	.181	.189

TABLE 743.—Secular Change of Horizontal Intensity, United States

Values of horizontal intensity in c.g.s. units for the places designated by the latitude and longitude in the first two columns for January 1 of the years in the heading.

Lat. °	Long. °	1855	1865	1875	1885	1895	1900	1905	1910	1915	1920	1925
25	80	.3064	.3054	.3034	.3003	.2968	.2946	.2916	.2870	.2805	.2749	.2704
25	90	....	....	.3107	.3087	.3051	.3026	.3000	.2962	.2910	.2863	.2825
25	100	....	....	.3188	.3157	.3125	.3108	.3086	.3055	.3017	.2980	.2950
31	80	.2652	.2650	.2644	.2624	.2606	.2591	.2567	.2526	.2465	.2419	.2382
31	90	.2817	.2787	.2752	.2750	.2728	.2710	.2687	.2653	.2603	.2561	.2527
31	100	.2922	.2887	.2852	.2838	.2816	.2802	.2784	.2755	.2720	.2688	.2662
31	110	.2963	.2933	.2903	.2876	.2855	.2847	.2832	.2809	.2784	.2760	.2738
37	80	.2184	.2187	.2197	.2189	.2182	.2177	.2159	.2130	.2086	.2049	.2022
37	90	.2332	.2314	.2292	.2302	.2292	.2284	.2266	.2239	.2198	.2167	.2142
37	100	....	....	.2407	.2403	.2391	.2383	.2368	.2345	.2317	.2292	.2272
37	110	....	....	.2519	.2502	.2488	.2481	.2471	.2453	.2433	.2414	.2396
37	120	.2612	.2602	.2592	.2573	.2557	.2553	.2547	.2536	.2522	.2506	.2492
43	70	.1612	.1631	.1654	.1667	.1682	.1689	.1692	.1680	.1662	.1644	.1632
43	80	.1682	.1682	.1692	.1710	.1718	.1718	.1710	.1693	.1667	.1647	.1632
43	90	....	....	.1792	.1798	.1794	.1791	.1783	.1766	.1741	.1723	.1708
43	100	....	....	.1958	.1956	.1952	.1949	.1940	.1924	.1905	.1888	.1873
43	110	....	....	.2110	.2100	.2092	.2087	.2082	.2070	.2057	.2043	.2029
43	120	....	....	.2242	.2228	.2217	.2215	.2213	.2206	.2196	.2183	.2172
47	70	.1365	.1372	.1381	.1402	.1424	.1434	.1444	.1443	.1432	.1422	.1415
47	80	....	.1367	.1367	.1387	.1397	.1402	.1404	.1394	.1380	.1369	.1362
49	90	....	....	.1280	.1286	.1291	.1294	.1295	.1287	.1276	.1268	.1262
49	100	....	....	.1458	.1458	.1457	.1458	.1458	.1450	.1440	.1431	.1422
49	110	....	....	.1639	.1635	.1631	.1632	.1632	.1626	.1618	.1609	.1600
49	120	....	....	.1847	.1838	.1831	.1832	.1834	.1831	.1825	.1816	.1808

TABLE 744.—Total Magnetic Intensity, United States

This table gives for the epoch January 1, 1925, the values of total intensity, F, expressed in c.g.s. units, corresponding to the longitudes in the heading and the latitudes in the first column.

φ \ λ	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	120°	125°
°													
19	....	....	.460	.463	.465	....	....	....	....	....	....	....	....
21	....	....	.474	.475	.477	.478	....	....	....	....	....	....	....
23	....	....	.491	.491	.490	.491	.488	.482	.475	....	....	....	....
25	....	....	.504	.508	.505	.504	.503	.496	.487	.477	.466	....	....
27	....	....	.516	.521	.521	.520	.516	.510	.501	.491	.479	.469	....
29	....	.513	.529	.533	.535	.536	.531	.522	.514	.504	.493	.482	....
31	....	.526	.540	.543	.549	.549	.543	.541	.529	.519	.507	.493	....
33	....	.537	.551	.552	.558	.559	.556	.552	.541	.530	.522	.507	....
35	....	.545	.560	.563	.570	.571	.569	.562	.553	.542	.528	.518	....
37	....	.558	.568	.571	.583	.582	.581	.572	.561	.553	.540	.533	....
39	....	.565	.576	.582	.586	.593	.589	.584	.577	.565	.556	.542	.529
41	....	.569	.583	.589	.601	.602	.596	.598	.584	.577	.564	.551	.536
43	....	.578	.586	.598	.602	.606	.597	.603	.594	.588	.573	.564	.548
45	.562	.581	.594	.603	.608	.613	.609	.608	.605	.592	.583	.573	.561
47	.570	.588	.599	.608	.620	.606	.619	.614	.609	.601	.588	.581	.572
49	.568	.587	.603	.611	.622	.624	.626	.621	.617	.602	.594	.585	.577

TABLE 745.—Secular Change of Total Intensity, United States

Values of total intensity in c.g.s. units for places designated by the latitudes and longitudes in the first two columns for January 1 of the years in the heading.

Lat.	Long.	1855	1865	1875	1885	1895	1900	1905	1910	1915	1920	1925
°	°											
25	80	.5407	.5385	.5339	.5262	.5209	.5190	.5175	.5170	.5136	.5102	.5081
25	90	....	....	.5232	.5210	.5137	.5115	.5131	.5134	.5107	.5070	.5045
25	100	....	....	.5159	.5107	.5078	.5069	.5064	.5051	.5025	.4990	.4961
31	80	.5792	.5781	.5749	.5657	.5606	.5589	.5575	.5554	.5496	.5456	.5434
31	90	.5786	.5749	.5697	.5666	.5627	.5613	.5604	.5602	.5557	.5516	.5488
31	100	.5676	.5647	.5608	.5570	.5543	.5537	.5535	.5516	.5479	.5439	.5409
31	110	.5453	.5424	.5388	.5348	.5333	.5330	.5317	.5291	.5261	.5225	.5193
37	80	.6094	.6080	.6080	.5977	.5910	.5901	.5878	.5851	.5790	.5739	.5707
37	90	.6111	.6089	.6040	.6028	.5977	.5977	.5963	.5947	.5889	.5848	.5814
37	100	....	....	.5922	.5889	.5863	.5863	.5860	.5838	.5795	.5752	.5717
37	110	....	....	.5722	.5687	.5676	.5670	.5657	.5629	.5593	.5560	.5525
37	120	.5539	.5524	.5512	.5484	.5474	.5459	.5437	.5414	.5381	.5353	.5326
43	70	.6208	.6214	.6189	.6091	.6011	.5994	.6005	.5962	.5898	.5828	.5780
43	80	.6402	.6361	.6345	.6287	.6201	.6183	.6166	.6136	.6079	.6024	.5981
43	90	....	....	.6341	.6306	.6231	.6227	.6217	.6194	.6142	.6097	.6061
43	100	....	....	.6269	.6224	.6190	.6191	.6184	.6155	.6110	.6072	.6034
43	110	....	....	.6091	.6053	.6039	.6030	.6020	.5985	.5948	.5917	.5881
43	120	....	....	.5842	.5818	.5806	.5784	.5767	.5740	.5706	.5673	.5644
47	70	.6468	.6398	.6298	.6209	.6115	.6106	.6126	.6100	.6025	.5947	.5883
47	80	....	.6575	.6486	.6417	.6298	.6288	.6289	.6244	.6189	.6132	.6085
49	90	....	....	.6561	.6506	.6421	.6408	.6404	.6364	.6310	.6270	.6241
49	100	....	....	.6498	.6441	.6389	.6385	.6377	.6334	.6283	.6243	.6212
49	110	....	....	.6245	.6209	.6188	.6178	.6172	.6129	.6087	.6053	.6019
49	120	....	....	.6075	.6051	.6028	.6009	.5994	.5957	.5916	.5882	.5851

TABLE 746.—Agonic Line, United States

The line of no declination (agonic line) is moving westward in the northern part of the country, but south of latitude 30° it is nearly stationary.

Lat. N.	Longitudes of the agonic line for the years—							
	1800	1850	1875	1890	1905	1915	1920	1925
°	°	°	°	°	°	°	°	°
25	....	....	....	75.5	76.1	77.4	77.4	77.1
30	....	....	....	78.6	79.7	80.0	80.1	79.7
35	....	76.7	79.0	79.9	81.7	82.7	82.8	83.0
6	75.2	77.3	79.7	80.5	82.8	84.4	84.5	84.4
7	76.3	77.7	80.6	82.2	83.5	84.0	84.0	84.0
8	76.7	78.3	81.3	82.6	83.6	84.1	84.1	84.0
9	76.9	78.7	81.6	82.2	83.6	83.9	84.0	84.2
40	77.0	79.3	81.6	82.7	84.0	84.3	84.5	84.6
1	77.9	80.4	81.8	82.8	84.6	85.1	85.2	85.2
2	79.1	81.0	82.6	83.7	84.8	85.3	85.4	85.8
3	79.4	81.2	83.1	84.3	85.0	85.4	85.6	85.8
4	79.8	....	83.3	84.9	85.5	85.8	86.0	86.1
45	....	....	83.6	85.2	86.0	86.2	86.4	86.6
6	....	....	84.2	84.8	86.4	86.3	86.6	86.8
7	....	....	85.1	85.4	86.4	86.6	86.8	87.1
8	....	....	86.0	85.9	86.5	87.2	87.6	87.7
9	....	....	86.5	86.3	87.2	88.0	88.2	88.2

TABLE 747.—Mean Magnetic Character of Each Month in the Years 1906 to 1930*

Means derived from daily magnetic characters based upon the following scale; 0, no disturbance; 1, moderate disturbance, and 2, large disturbance.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year Mean
1906	0.45	0.90	0.68	0.63	0.58	0.56	0.69	0.63	0.79	0.59	0.55	0.71	0.65
1907	.69	.83	.58	.55	.72	.67	.67	.66	.68	.71	.61	.53	.66
1908	.64	.71	.87	.68	.82	.66	.49	.77	.89	.53	.60	.47	.68
1909	.76	.63	.79	.49	.59	.54	.53	.65	.70	.69	.49	.58	.62
1910	.58	.71	.81	.68	.72	.53	.55	.81	80	.96	.77	.76	.72
1911	.78	.89	.78	.76	.70	.53	.61	.53	.50	.59	.49	.45	.63
1912	.42	.49	.45	.45	.47	.47	.41	.49	.47	.46	.45	.43	.46
1913	.51	.53	.53	.54	.45	.45	.42	.46	.58	.57	.42	.36	.48
1914	.46	.50	.62	.50	.37	.52	.61	.61	.53	.64	.60	.46	.54
1915	.53	.64	.68	.61	.58	.61	.47	.60	.59	.77	.82	.54	.62
1916	.61	.56	.86	.68	.75	.67	.62	.75	.75	.76	.83	.65	.71
1917	.81	.69	.59	.63	.66	.55	.61	.85	.61	.74	.53	.72	.67
1918	.63	.78	.73	.79	.68	.56	.69	.77	.88	.85	.87	.88	.76
1919	.78	.81	.89	.70	.82	.55	.54	.70	.83	.91	.52	.56	.72
1920	.62	.52	.78	.65	.57	.43	.51	.61	.87	.65	.58	.65	.62
1921	.54	.51	.68	.67	.83	.55	.54	.58	.50	.63	.62	.65	.76
1922	.65	.74	.79	.75	.57	.62	.66	.71	.69	.68	.47	.42	.65
1923	.48	.61	.53	.44	.47	.50	.42	.36	.52	.55	.42	.50	.48
1924	.64	.56	.64	.43	.54	.64	.55	.41	.67	.52	.54	.40	.54
1925	.44	.42	.42	.52	.47	.74	.55	.61	.71	.82	.48	.57	.56
1926	.84	.85	.85	.75	.60	.53	.49	.50	.75	.67	.46	.54	.65
1927	.62	.66	.80	.60	.65	.47	.56	.61	.77	.84	.35	.63	.63
1928	.44	.62	.48	.52	.75	.72	.72	.56	.75	.83	.65	.54	.63
1929	.47	.82	.85	.54	.61	.56	.66	.55	.75	.85	.71	.71	.67
1930	.65	.49	.35	.38	.37	.29	.22	.25	.32	.34	.36	.26	.37
1931	.54	.62	.59	.45	.54	.65	.55	.68	.82	.95	.83	.74	.66

* Compiled from annual reviews of the "Caractère magnétique de chaque jour," prepared by the Royal Meteorological Institute of the Netherlands for the International Commission for Terrestrial Magnetism.

TABLE 748.—Elements and Constants of Atmospheric Electricity

(Prepared by O. H. Gish, Department of Terrestrial Magnetism, Carnegie Institution of Washington, 1930.)

The elements of atmospheric electricity show variations, both regular and irregular. Over land the irregular variations are very pronounced and the regular variations differ notably from place to place, in marked contrast to the corresponding characteristics over the ocean. Therefore, and because of the wider and more uniform geographical distribution of ocean observations, it seems best to give the greater weight to the ocean data when attempting to arrive at values characterizing world-wide conditions. Because of the wide variation from place to place in the means from land stations, due to local factors, a general mean of these is of questionable significance. Hence it seems better to indicate the extremes of station means in the case of elements for which the data are sufficiently abundant.

Certain disparities which will be found between these and other published tables [see references (2) and (21)] arise largely from the inclusion of more recent data. The references to authorities have been selected with a view to being helpful in following up the literature rather than to assigning due credit for the original investigations.

Of the atmospheric-electric elements the potential gradient has been the most extensively observed. The sign of the average gradient is everywhere such as to drive positive ions toward the earth. The periodic variations in this element are of great interest because of their apparent relation with cosmic phenomena. Thus the potential gradient apparently increases with increase in the Wolfer sun-spot numbers, varies throughout the year, the maxima in monthly means occur everywhere, with few exceptions, at the time of northern winter, and the corresponding minima occur at the time of northern summer. The diurnal variation observed over the oceans is everywhere in phase when considered on a common-time basis, except for a minor phase-shift that depends upon the season. This diurnal variation derived from observations made on the *Carnegie* during 1915 to 1921 is given by the Fourier expression[1] $\Delta P/P = 0.15 \sin(\theta + 186^\circ) + 0.03 \sin(2\theta + 237^\circ)$ where θ is reckoned at 15° per hour beginning at 0^h Greenwich mean civil time.

No general expression that will approximately characterize the diurnal variation over land can be given. There variations determined by local factors are apparently superimposed upon a variation of the same world-wide character as that found to prevail over the oceans [see reference (5)].

[1] From revised calculations in unpublished manuscript of the Department of Terrestrial Magnetism.

TABLE 749.—Atmospheric-Electric Data

Element	Symbol	Means	Units	Variations	Authority
Potential gradient	P	Land: 67 to 317	volts/m	Range — Per cent of mean Annual 22 to 145 Diurnal 35 to 120	3 4, 5
		Sea: 128	"	Annual 13 Diurnal 35	1, 2 1
		Free air		Percentage of surface values at various altitudes 0 km 100; 6 km 8 3 " 17; 9 " 4	3
Air-conductivity total	$\lambda = \lambda_+ + \lambda_-$	Land: 1 to 5	c.g.s.e. $\times 10^{-4}$	Variations determined chiefly by local factors	3, 6
		Sea: 2.6	" "	Variations small and chiefly irregular	1
		Free air		Ratio of value at various altitudes to that at surface 0 km 1; 6 km 20 3 " 8; 9 " 38	7
Ratio of positive to negative conductivity	λ_+/λ_-	Land: 1.12 Sea: 1.26			3, 6 1
Air-earth current density	$i = \lambda P/30000$	Land: 7.0 Sea: 11.0	c.g.s.e. $\times 10^{-7}$		3 1
Density of small ions: Positive	n_+	Land: 750 Sea: 600	ions/cm³ "		3, 6 1
Negative	n_-	Land: 650 Sea: 500	" "		3, 6 1
	$(n_+ + n_-)/2$	Free air		Values at various altitudes 2 km 1300 4 " 1900 5 " 2300	10
Ratio of positive to negative ionic density	$p = n_+/n_-$	Land: 1.23 Sea: 1.23			3, 6 1

TABLE 749 (*continued*).—Atmospheric-Electric Data

Element	Symbol	Means		Units	Authority
Space-charge, over land	ρ	At surface:* -2000 to $+1000$		10^{-10} c.g.s.e./cm³	
	$\rho = -\left(\frac{dP}{dh}/1.2\pi\right) \times 10^{-10}$ (For h = height in km)	Free air:	ρ		
		0 to 3 km	9.0	"	
		3 to 6	0.9	"	
		6 to 9	0.4	"	3
Mobility of small ions:	$k_+ = \lambda_+/300\ en_+$				
Positive	k_+	Land:	0.9	cm/sec./volt/cm	3, 6
		Sea:	1.6	"	1
Negative	k_-	Land:	1.0	"	3, 6
		Sea:	1.7	"	1
Rate of formation of ion-pairs	q	Over land: Ra and Th products in air			
		α rays	4.6	ions/cm³/sec.	
		β rays	0.2	"	
		γ rays	0.15	"	
		Radioactive matter in the Earth's crust			
		β rays	0.1	"	
		γ rays	3.0	"	
		Penetrating radiation	1.5	"	
		Total	9.55	"	3, 6
		At sea: Penetrating radiation	1.5	"	
		(?)	0.7	"	
		Total	2.2	"	8

* The sign and magnitude of surface values are exceedingly variable from place to place.

TABLE 750.—Ionic equilibrium in the atmosphere

Equilibrium for atmospheric ionization occurs when $q = \alpha n^2 + \eta_1 N_0 n + \eta_2 N n$, where n and N are the number of pairs of small and large ions, and N_0 the number of uncharged nuclei; α, η_1, η_2, are coefficients of recombination of small ions with small ions, with uncharged nuclei, and with large ions. If for both small and large ions the positive and negative are equally abundant, then $N_0/N = \eta_2/\eta_1 = 1.28$ [reference (12)]. When $n/N \ll 2\eta_2/\alpha$, the equilibrium-condition is expressed by $q = \beta n$; β is designated the diminution-constant; $1/\beta = \Theta$ is the "average life" of a small ion in air which contains an abundance of large ions; Θ varies inversely as N.

α: 1.55×10^{-6} cm³/sec. [see reference (11)]
η_1: 5×10^{-6} " } [see references (8), (12), (13)]
η_2: 6×10^{-6} "
Θ: Over land,
 Average, 30 sec. } [see reference (8)]
 Extremes, 10 to 60 sec.
 Over sea, 230 sec.
N: Over land, 500 to 50,000 ions/cm³ [see references (13), (14)]
Aitken nuclei, number per cm³:
 Over open country, up to 10^5 [see reference (16)]
 Over mid-ocean, about 800 [see reference (15)]
 In free air,
 Altitude 1 km 6,000 5 km 50 } see reference (17)
 3 km 200 8.5 km about 5

TABLE 751.—Thunderstorm Electricity

Quantity discharged by a lightning flash: 10 to 50 coulombs; average 20 coulombs.
Energy of a lightning flash: 10^{17} ergs.
Potential difference between discharge points: 10^9 volts.
Potential gradient at earth's surface beneath a thundercloud: 10^4 volts/meter.
(The charge producing this field more frequently negative than positive).
Number of lightning discharges over entire earth each second: At least 100.
[see reference (18)].

Duration of lightning flash: More than 0.001 sec [see reference (19)].

TABLE 752.—Charge on Rain and Snow

Specific net charge on precipitation:

Average, 0.5 c.g.s.e./gm.
Maximum observed, 20 c.g.s.e./gm.
[see reference (3)].

Specific charge on individual raindrops or snowflakes:

Rain, + 2.7 to − 3.2 c.g.s.e./gm.
Snow, + 11.6 to − 8.1 c.g.s.e./gm.
[see reference (20)].

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For current literature consult Journal of Terrestrial Magnetism and Atmospheric Electricity, Baltimore (vol. 38 in progress 1933), and Zeitschrift für Geophysik, Braunschweig.

TABLE 753.—Ionization in the Upper Atmosphere of the Earth

(Hulbert, Phys. Rev., 34, 1167, 1929; 35, 24, 1930; 37, 1, 1931.)

Each cm^3 of the upper atmosphere is assumed approximately electrically neutral. Above 60 km the ionization is assumed to be caused by solar ultra-violet light; below, by cosmic radiation. At any height z km above sea-level, let the numbers per cm^3 of singly-charged positive ions, negative ions and electrons be y_+, y_- and y_e. Then $y_+ = y_- + y_e$, and since y_e is in general small compared to y_-, the values of y_+ and y_- are nearly equal. Above 60 km the positive ion densities y_+ are given in Table 754. The electron density y_e increases with z to a max. value y_e at a height z_m; y_e max. and z_m are given in Table 754*a*. Above and below the max. y_e can not yet be estimated with certainty. The values for y_+ and y_e max. may be correct within a factor of 2; a zero value means a small value. The tables are for average equinoctial conditions and solar quiescence, halfway between the periods of max. and min. solar activity. The values should be increased and reduced by roughly 25% to refer to epochs of max. and min. solar activity. During magnetic storms the ionization increases, being perhaps double the tabular values for a severe storm. In polar regions it is probably not greatly different from that for latitude 60°. The seasonal changes are small at the equator. In temperate latitudes for winter and summer use the values for latitudes about 20° higher and lower. Below 60 km the ionization due to cosmic radiation is independent of the latitude, hour of the day, solar activity, etc., and y is 8×10^2, 1.6×10^3, 1.9×10^3, 2.2×10^3, 2.9×10^3, and 3.5×10^3 at 0, 10, 20, 30, 40, and 50 km.

TABLE 754.—Ion Density y_+ in the Upper Atmosphere

	z	Geographic latitude. 0°	40°	60°
Noon	200 km	0	0	0
	190	4.7×10^9	4.0×10^9	0
	180	4.7×10^9	4.0×10^9	0
	170	4.7×10^9	4.0×10^9	3.1×10^9
	160	4.7×10^9	4.0×10^9	3.1×10^9
	150	4.7×10^9	4.0×10^9	3.1×10^9
	140	7.0×10^8	4.0×10^8	3.1×10^9
	130	2.3×10^8	1.4×10^8	3.1×10^9
	120	9.1×10^7	6.7×10^7	5.1×10^7
	110	3.6×10^7	2.7×10^7	2.3×10^7
	100	1.4×10^7	1.2×10^7	7.1×10^6
	90	5.8×10^6	5.4×10^6	2.7×10^6
	80	2.1×10^6	1.6×10^6	1.1×10^6
3 p. m. or 9 a. m.	200 km	0	0	0
	190	3.0×10^9	0	0
	180	3.0×10^9	2.8×10^9	0
	170	3.0×10^9	2.8×10^9	2.3×10^9
	160	3.0×10^9	2.8×10^9	2.3×10^9
	150	3.0×10^9	2.8×10^9	2.3×10^9
	140	2.8×10^8	2.8×10^9	2.3×10^9
	130	1.1×10^8	4.0×10^8	2.3×10^9
	120	4.6×10^7	1.0×10^8	1.1×10^8
	110	1.9×10^7	3.4×10^7	3.7×10^7
	100	9.1×10^6	1.2×10^7	1.1×10^7
	90	2.8×10^6	4.5×10^6	3.1×10^6
	80	1.2×10^6	1.8×10^6	1.0×10^6
6 p. m. or 6 a. m.	150 km	0	0	0
	140	1.7×10^9	0	0
	135	1.7×10^9	1.7×10^9	1.6×10^9
	130	1.7×10^9	1.7×10^9	1.6×10^9
	120	1.7×10^9	1.7×10^9	1.6×10^9
	115	1.7×10^9	1.7×10^9	1.6×10^9
	110	5.1×10^7	1.7×10^9	1.6×10^9
	100	1.3×10^7	1.9×10^7	1.4×10^7
	90	2.9×10^6	3.9×10^6	3.4×10^6
	80	8.0×10^5	8.4×10^5	8.1×10^5

TABLE 754 (*continued*).—Ion Density y_+ in the Upper Atmosphere

	z	Geographic latitude. 0°	40°	60°
9 p. m.	170 km	0	0	0
	160	1.7×10^9	0	0
	150	1.7×10^9	0	0
	140	0	1.7×10^9	1.6×10^9
	130	0	1.7×10^9	1.6×10^9
	120	0	0	0
	115	5.2×10^7	0	0
	110	2.4×10^7	3.8×10^7	3.3×10^7
	100	5.9×10^6	1.0×10^7	9.2×10^6
	90	1.3×10^6	2.1×10^6	1.9×10^6
	80	3.8×10^5	5.1×10^5	4.6×10^5
Midnight	170 km	0	0	0
	160	1.6×10^9	0	0
	150	1.6×10^9	0	0
	145	0	1.2×10^9	1.1×10^9
	135	0	1.2×10^9	1.1×10^9
	125	0	0	0
	115	3.4×10^7	0	0
	110	1.6×10^7	2.3×10^7	2.1×10^7
	100	3.6×10^6	2.3×10^6	6.5×10^6
	90	8.7×10^5	1.8×10^6	1.3×10^6
	80	4.6×10^5	3.7×10^5	3.1×10^5
3 a. m.	170 km	0	0	0
	160	1.5×10^9	0	0
	150	1.5×10^9	0	0
	145	0	1.0×10^9	9.0×10^8
	135	0	1.0×10^9	9.0×10^8
	125	0	0	0
	115	2.4×10^7	0	0
	110	1.0×10^7	1.5×10^7	1.4×10^7
	100	3.1×10^6	5.3×10^6	4.9×10^6
	90	5.5×10^5	1.1×10^6	9.4×10^5
	80	1.9×10^5	2.8×10^5	2.2×10^5

TABLE 754A.—Maximum Electron Density y_e Max. in the Upper Atmosphere

	Geographic latitude 0° Z_m	0° y_e max.	40° Z_m	40° y_e max.	60° Z_m	60° y_e max.
Noon	195 km	3.2×10^5	195 km	2.4×10^5	175 km	1.6×10^5
3 p. m.	195	2.5×10^5	195	1.9×10^5	175	1.3×10^5
6 p. m.	144	1.2×10^5	140	0.9×10^5	140	0.6×10^5
9 p. m.	165	1.1×10^5	145	0.1×10^5	145	0
Midnight	165	1.0×10^5	145	0	145	0
3 a. m.	165	0.8×10^5	145	0	145	0
6 a. m.	144	1.0×10^5	140	0.8×10^5	140	0.5×10^5
9 a. m.	195	2.0×10^5	195	1.5×10^5	175	1.0×10^5

Table 755

MISCELLANEOUS ASTRONOMICAL DATA

Tropical (ordinary) year	$= \{365.24219879 - 0.0000000614\ (t - 1900)\}$ days.
Sidereal year	$= \{365.25636042 + 0.0000000011\ (t - 1900)\}$ days.
Anomalistic year	$= \{365.25964134 + 0.0000000304\ (t - 1900)\}$ days.
Eclipse year	$= \{346.620000 + 0.00000036\ (t - 1900)\}$ days.
Synodical (ordinary) month	$= \{29.530588102 - 0.00000000294\ (t - 1900)\}$ days.
Sidereal month	$= \{27.321660890 - 0.00000000252\ (t - 1900)\}$ days.
Sidereal day (ordinary, two successive transits of vernal equinox, might be called equinoctial day)	= 86164.09054 mean solar seconds. = 23 h. 56 m. 4.09054 mean solar time.
Two successive transits of same fixed star	= 86164.09966 mean solar seconds.
1930, Julian Period = 6643.	
January 1, 1933, Julian-day number = 2427074. See p. 603.	
Solar parallax	$= 8.7958'' \pm 0.002''$ (Weinberg). 8.807 ± 0.0027 (Hincks, Eros). 8.799 (Sampson, Jupiter satellites; Harvard observations). 8.80 Paris conference; $8.8032'' \pm 0.0013$.*
Lunar parallax	$= 3422.63'' = 57'\ 2.63''$ (Newcomb). $= \pi' = 3422.519'' \pm 0.009$ (De Sitter).*
Mean distance earth to sun	= 149500000 kilometers = 92900000 miles.
Mean distance earth to moon	= 60.2678 terrestrial radii. = 384411 kilometers = 238862 miles.
Light traverses mean radius of earth's orbit in 498.7 sec.	
Velocity of light (mean value) in vacuo, 299796 ± 4 km/sec. (Michelson).	
Constant of aberration	$= 20.4874'' \pm 0.005''$. 20.47 Paris conference (work of Doolittle and others indicates value not less than 20.51).
Light year	$= 9.5 \times 10^{12}$ kilometers $= 5.9 \times 10^{12}$ miles.
Parsec, distance star whose parallax is 1 sec.	$= 31 \times 10^{12}$ km $= 19.2 \times 10^{12}$ miles.
General precession	$= 50.2564'' + 0.000222\ (t - 1900)''$ (Newcomb).
General precession	$50.2486'' \pm 0.0010$ (De Sitter, 1927).
Planetary precession	$= \lambda = 0.1228'' \pm 0.0012$ (De Sitter, 1927).
Lunar-solar precession	$= p' = 50.3714'' \pm 0.0016$ (De Sitter, 1927). Of this 0.0191″, Einstein, orbital motion earth.*
True lunar-solar precession	$= p = 50.3523$, sun, moon, earth's attraction.*
Obliquity of ecliptic	$= 23°\ 27'\ 8.26'' - 0.4684\ (t - 1900)''$ (Newcomb).
Constant of nutation	$= 9.21''$ (Paris conference); $9.208'' \pm 0.003$.*
Constant in long.	$= \Delta\phi = (-17.234'' - .017''T) \sin \Omega$ } Jackson,
Constant in obliquity	$= \Delta\epsilon = (+9.218 + .0009T) \cos \Omega$ } M. N., 1930.
Latter has relativity correction; T centuries from 1900.	
Gravitation constant	$= (6.670 \pm 0.002) \times 10^{-8}$ dyne cm^2 g^{-2} (Heyl, 1930).
Eccentricity earth's orbit	$= e = 0.01675104 - 0.0000004180\ (t - 1900) - 0.0000000000126\ (t - 1900)^2$.
Eccentricity moon's orbit	$= e_2 = 0.05490056$ (Brown).
Inclination moon's orbit	$= I = 5°\ 8'\ 43.5''$ (Brown).
Delaunay's $\gamma = \sin \frac{1}{2} I$	$= 0.04488716$ (Brown).
Lunar inequality of earth	$= L = 6.454''$; 6.459 ± 0.005.*
Parallactic inequality moon	$= Q = 124.785''$ (Brown).
Mean sidereal motion of moon's node in 365.25 days	$= -19°\ 21'\ 19.3838'' + 0.001294\ (t - 1900)''$.
Pole of Milky Way	= R. A., 12 h. 48 m.; Dec., + 27°. See p. 604.
d (lunar perigee)	$= +6.386''$.
d (lunar node)	$= -5.977''$.

* De Sitter, Bull. Astron. Inst., Netherlands, 4, 57, 1927.

MISCELLANEOUS ASTRONOMICAL DATA AND FORMULAE

If δ = declination, t, hour angle measured west from meridian, h, altitude, ϕ, latitude and A, azimuth measured from S. point through W. Then

$$\left.\begin{aligned} \sin h &= \sin\phi\sin\delta + \cos\phi\cos\delta\cos t \\ \cos h\cos A &= -\cos\phi\sin\delta + \sin\phi\cos\delta\cos t \\ \cos h\sin A &= \cos\delta\sin t \end{aligned}\right\}\text{given } \delta, t, \phi$$

$$\left.\begin{aligned} \sin\delta &= \sin\phi\sin h - \cos\phi\cos h\cos A \\ \cos\delta\cos t &= \cos\phi\sin h + \sin\phi\cos h\cos A \\ \cos\delta\sin t &= \cos h\sin A \end{aligned}\right\}\text{given } h, A, \phi$$

Refraction.— r in ($''$) = $[983 \times$ (barometer in in.)/(460 + $t°$ F.)] $\tan Z$, where Z = zenith distance. Error $< 1''$, $Z < 75°$, ordinary t and pressure.

Twilight.—Considered to end when 1st mag. star is visible in zenith. Lasts until sun is about 18° below horizon; lat. 40°, equivalent to about $1\frac{1}{2}$ to 2 hr.; latitude $> 50°$, lasts until midnight.

Dip of horizon.—In minutes of arc = $\sqrt{\text{elevation in ft.}}$

Horizon.—Distance at sea is approximately, miles = $\sqrt{(\frac{3}{4})h \text{ in feet}}$; no account taken of refraction, actual distance greater.

Date line.—180° from meridian of Greenwich. Ships crossing it from the east, skip a day; going east, count same day twice.

Velocity, equatorial point on earth.—Because of rotation: 1000 mi./hr. = 1500 ft./sec. = 1600 km/m = 450 m/sec. In orbit: 18.5 mi./sec. = 30 km/sec.

Latitude variation.—Direction of axis of the earth in space is invariable but a variation in latitude is caused by a shift of the earth's body about this axis. There are two components, one, annual (narrow ellipse, varying in form and position, about 10 m long on the earth's surface) probably meteorological in origin; the other, circular, about 8 m in diameter, period 433 days, due to noncoincidence of axis of figure and of rotation.

Magnitudes.—(Apparent, m). The light of an average 1st magnitude star was found to be physically 100 times as intense as that of a 6th. $\sqrt[5]{100}$ or 2.512 has been adopted as the light ratio between two stars differing in magnitude by unity ($\log_{10} 0.400 = 2.512$). If l_m = approximate brightness of star of magnitude m, l_n of n, then, $l_n/l_m = (2.512)^{m-n}$ whence

$m - n = 2.5\ (\log l_n - \log l_m)$; if l_0 = brightness 0 mag. star $\log\ (\log_m/\log_0) = -0.4\,m$.

Magnitudes.—("Absolute," M.) The "absolute" magnitude of a star is its magnitude reduced to a standard distance, 10 parsecs (Int. Astron. Union, 1922). $M - m = 2.5$ (log amt. light rec'd)/(log amt. if at unit distance) $= 5 \log p - 5 \log p_0$ where p, p_0 are observed parallax and that for standard distance; $p_0 = 0.1 \therefore M = m + 5 + 5 \log p$. β Orionis, $M = -5.5$ is brightest star.

Color index.—We have visual, photographic, and bolometric (radiometric) magnitudes. The zero of the photographic scale is taken so that both the photographic and visual scale coincide, on the average, for stars of spectrum class AO and $m = 5.5$ to 6.5. Difference of magnitudes on the two scales is the color index, photovisual is + for red, — for blue stars and may amount to + 2.0 mag.

Heat index.—Radiometric (heat or bolometric), zero taken to agree with Class AO, (radiometric — visual magnitude) = head index, + for red stars.

Purkinje effect.—Two colored lights appearing equally bright at a certain brightness, when brightness decreased equally physically, the bluer appears brighter.

CALENDARS

TABLE 757.—Julian Day Calendar

Proposed by Scaliger, 1582. Days are numbered consecutively from Greenwich mean noon on January 1, 4713 B. C. Advantage: difference between two dates becomes merely difference between two Julian day numbers. As our civil and astronomical days begin at midnight, the numbers from the table must be increased by one after noon of date.

Julian Day No. = 2420000 + no. in table. Jan. 0, etc., at head of col. means Jan. 0 until noon, then Jan. 1, etc.

Year	Jan. 0	Feb. 0	Mar. 0	Apr. 0	May 0	June 0	July 0	Aug. 0	Sept. 0	Oct. 0	Nov. 0	Dec. 0
1920.........	2324	2355	2384	2415	2445	2476	2506	2537	2568	2598	2629	2659
1921.........	2690	2721	2749	2780	2810	2841	2871	2902	2933	2963	2994	3024
1922.........	3055	3086	3114	3145	3175	3206	3236	3267	3298	3328	3359	3389
1923.........	3420	3451	3479	3510	3540	3571	3601	3632	3663	3693	3724	3754
1924.........	3785	3816	3845	3876	3906	3937	3967	3998	4029	4059	4090	4120
1925.........	4151	4182	4210	4241	4271	4302	4332	4363	4394	4424	4455	4485
1926.........	4516	4547	4575	4606	4636	4667	4697	4828	4759	4789	4820	4850
1927.........	4881	4912	4940	4971	5001	5032	5062	5093	5024	5154	5185	5215
1928.........	5246	5277	5306	5337	5367	5398	5428	5459	5490	5520	5551	5581
1929.........	5612	5643	5671	5702	5732	5763	5793	5824	5855	5885	5916	5946
1930.........	5977	6008	6036	6067	6097	6128	6158	6189	6220	6250	6281	6311
1931.........	6342	6373	6401	6432	6462	6493	6523	6554	6585	6615	6646	6676
1932.........	6707	6738	6767	6798	6828	6859	6889	6920	6951	6981	7012	7042
1933.........	7073	7104	7132	7163	7193	7224	7254	7285	7316	7346	7377	7407
1934.........	7438	7469	7497	7528	7558	7589	7619	7650	7681	7711	7742	7772
1935.........	7803	7834	7862	7893	7923	7954	7984	8015	8046	8076	8107	8137
1936.........	8168	8199	8228	8259	8289	8320	8350	8381	8412	8442	8473	8503
1937.........	8534	8565	8593	8624	8654	8685	8715	8746	8777	8807	8838	8868
1938.........	8899	8930	8958	8989	9019	9050	9080	9111	9142	9172	9203	9233
1929.........	9264	9295	9323	9354	9384	9415	9445	9476	9507	9537	9568	9598
1940.........	9629	9660	9689	9720	9750	9781	9811	9842	9873	9903	9934	9964

TABLE 758.—Perpetual Calendar

To find the calendar for any year, e.g., 1924, divide century part of year (19) by 4 and with the remainder (3) enter Dominical Letters table. Use line (3) of lower sections of table corresponding to value of remainder, taking the Dominical Letter corresponding to the column in upper parts of table containing the last two figures of the year in question (24). This being a leap year we find two letters (F) to be used with Jan. and Feb., (E) with the rest of the year. In the second part of the table this Dominical Letter indicates which schedule of week days is to be used with the month in question. E.g., Jan. 1, 1924, comes on Tuesday; July 4 on Friday.

Year No.																
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
		29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
		57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
		85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
(1)	C	B	A	G	FE	D	C	B	AG	F	E	D	CB	A	G	F
(2)	E	D	C	B	AG	F	E	D	CB	A	G	F	ED	C	B	A
(3)	G	F	E	D	CB	A	G	F	ED	C	B	A	GF	E	D	C
(4)	BA	G	F	E	DC	B	A	G	FE	D	C	B	AG	F	E	D

Year No.													
	16	17	18	19	20	21	22	23	24	25	26	27	28
	44	45	46	47	48	49	50	51	52	53	54	55	56
	72	73	74	75	76	77	78	79	80	81	82	83	84
(1)	ED	C	B	A	GF	E	D	C	BA	G	F	E	DC
(2)	GF	E	D	C	BA	G	F	E	DC	B	A	G	FE
(3)	BA	G	F	E	DC	B	A	G	FE	D	C	B	AG
(4)	CB	A	G	F	ED	C	B	A	GF	E	D	C	BA

Month	Dominical letter						
Jan., Oct.	A	B	C	D	E	F	G
Feb., Mar., Nov.	D	E	F	G	A	B	C
Apr., July	G	A	B	C	D	E	F
May	B	C	D	E	F	G	A
June	E	F	G	A	B	C	D
Aug.	C	D	E	F	G	A	B
Sept., Dec.	F	G	A	B	C	D	E
1 8 15 22 29	Sun.	Sat.	Fri.	Thurs.	Wed.	Tues.	Mon.
2 9 16 23 30	Mon.	Sun.	Sat.	Fri.	Thurs.	Wed.	Tues.
3 10 17 24 31	Tues.	Mon.	Sun.	Sat.	Fri.	Thurs.	Wed.
4 11 18 25	Wed.	Tues.	Mon.	Sun.	Sat.	Fri.	Thurs.
5 12 19 26	Thurs.	Wed.	Tues.	Mon.	Sun.	Sat.	Fri.
6 13 20 27	Fri.	Thurs.	Wed.	Tues.	Mon.	Sun.	Sat.
7 14 21 28	Sat.	Fri.	Thurs.	Wed.	Tues.	Mon.	Sun.

NOTE—For general discussion of calendars, see British Nautical Almanac, p. 734 et seq., 1931.

RIGHT ASCENSION, DECLINATION INTO GALACTIC COORDINATES

Condensed from Tavole calcolate dal Emanuelli (1929), Secretario della Specola Vaticano. Galactic pole, R. A., 191.1°, dec. +26.6° (Newcomb, 1904). The zero point of the tables takes the longitude of the solar apex as 0° (R. A., 270°, dec., +30°, 1900). To reduce the galactic longitude as reckoned from the intersection of the galactic plane with equator, add 23.6° to "Long."; as reckoned from α Cygni (proposed by Int. Astron. Union, 1925), add +27.9, 1900, (+23.7, 1930).

Dec. \ R. A.	0h Long.	0h Lat.	1h Long.	1h Lat.	2h Long.	2h Lat.	3h Long.	3h Lat.	4h Long.	4h Lat.
	°	°	°	°	°	°	°	°	°	°
+90	66.4	+26.8	66.4	+26.8	66.4	+26.8	66.4	+26.8	66.4	+26.8
+80	64.4	+17.0	67.1	+16.8	69.8	+17.3	72.3	+18.4	74.4	+20.0
+70	62.6	+ 7.1	67.7	+ 6.8	72.8	+ 7.7	77.6	+ 9.8	81.7	+12.9
+60	60.9	− 2.7	68.4	− 3.1	75.7	− 1.8	82.6	+ 1.2	88.7	+ 5.6
+50	59.2	−12.6	69.0	−13.1	78.7	−11.4	87.6	− 7.5	95.4	− 1.8
+40	57.2	−22.4	69.7	−23.1	81.8	−20.9	92.8	−16.1	102.2	− 9.2
+30	55.0	−32.2	70.4	−33.1	85.4	−30.4	98.5	−24.6	109.3	−16.4
+20	52.3	−42.0	71.4	−43.1	89.7	−39.7	105.0	−32.8	116.9	−23.4
+10	48.6	−51.6	72.8	−53.0	95.4	−48.9	112.8	−40.6	125.4	−30.0
0	42.9	−61.1	75.0	−62.9	103.6	−57.6	122.6	−47.8	134.9	−35.9
−10	32.4	−70.2	79.5	−72.8	116.7	−65.5	135.2	−53.9	146.0	−41.0
−20	7.8	−77.8	94.9	−82.3	139.0	−71.4	151.3	−58.2	158.6	−44.9
−30	315.7	−79.7	200.3	−85.3	171.7	−73.1	170.6	−60.1	172.6	−47.2
−40	278.5	−73.9	233.6	−76.4	201.3	−69.5	190.3	−59.0	187.4	−47.7
−50	263.6	−65.3	240.1	−66.6	219.5	−62.7	207.4	−55.3	201.9	−46.3
−60	256.3	−55.9	242.9	−56.7	230.3	−54.4	220.9	−49.5	215.3	−43.1
−70	251.9	−46.3	244.5	−46.7	237.3	−45.4	231.4	−42.6	227.1	−38.6
−80	248.8	−36.6	245.6	−36.8	242.4	−36.2	239.6	−34.9	237.4	−33.1
−90	246.4	−26.8	246.4	−26.8	246.4	−26.8	246.4	−26.8	246.4	−26.8

Dec. \ R. A.	5h Long.	5h Lat.	6h Long.	6h Lat.	7h Long.	7h Lat.	8h Long.	8h Lat.	9h Long.	9h Lat.
	°	°	°	°	°	°	°	°	°	°
+90	66.4	+26.8	66.4	+26.8	66.4	+26.8	66.4	+26.8	66.4	+26.8
+80	76.1	+22.1	77.2	+24.5	77.6	+27.0	77.3	+29.6	76.2	+32.0
+70	85.1	+16.8	87.5	+21.4	88.8	+26.4	88.7	+31.5	87.1	+36.4
+60	93.7	+11.2	97.4	+17.7	99.8	+24.9	100.5	+32.3	99.1	+39.7
+50	101.8	+ 5.3	106.9	+13.6	110.4	+22.6	112.3	+32.1	112.0	+41.7
+40	109.9	− 0.6	116.0	+ 9.1	120.6	+19.7	123.9	+30.7	125.5	+42.1
+30	117.9	− 6.6	124.9	+ 4.4	130.5	+16.1	135.1	+28.4	138.8	+41.0
+20	126.2	−12.4	133.7	− 0.4	140.0	+12.2	145.7	+25.2	151.4	+38.5
+10	134.8	−18.0	142.4	− 5.2	149.2	+ 7.9	155.7	+21.3	162.9	+34.6
0	144.0	−23.1	151.3	− 9.9	158.2	+ 3.5	165.2	+16.8	173.3	+29.8
−10	153.8	−27.7	160.5	−14.3	167.1	− 1.1	174.2	+11.9	182.6	+24.3
−20	164.4	−31.5	170.1	−18.4	176.0	− 5.6	182.9	+ 6.8	191.2	+18.3
−30	175.8	−34.4	180.0	−22.0	185.1	− 9.9	191.4	+ 1.4	199.1	+11.9
−40	187.9	−36.2	190.4	−24.9	194.4	−14.1	199.8	− 3.9	206.7	+ 5.2
−50	200.3	−36.7	201.3	−27.1	204.1	−17.8	208.4	− 9.2	214.2	− 1.5
−60	212.7	−35.9	212.5	−28.5	214.1	−21.1	217.2	−14.2	221.6	− 8.1
−70	224.7	−33.9	223.9	−28.9	224.5	−23.8	226.4	−19.0	229.3	−14.7
−80	235.9	−30.8	235.3	−28.3	235.3	−25.7	236.1	−23.2	237.5	−20.9
−90	246.4	−26.8	246.4	−26.8	246.4	−26.8	246.4	−26.8	246.4	−26.9

N. B.—The reductions for plus and minus 90° are independent of the right ascension and declination and respectively: 66°.4, +26°.8 and 246°.4, −26°.9. The Galactic pole has been variously taken: Newcomb 12^h44^m, +26°.6; Gould, 12^h42^m, +32°; Searle, 12^h40^m, +28°, for tables of conversion see Harvard Annals, 56, 1912; Kapteyn, 12^h41^m, +27°.3; Van Rhijn, 12^h56^m, +25°, for tables, see Gröningen Publications, 43, 1929.

RIGHT ASCENSION, DECLINATION INTO GALACTIC COORDINATES

	10h Long.	10h Lat.	11h Long.	11h Lat.	12h Long.	12h Lat.	13h Long.	13h Lat.	14h Long.	14h Lat.
	°	°	°	°	°	°	°	°	°	°
+80	74.3	+34.1	71.8	+35.7	68.8	+36.6	65.6	+36.8	62.4	+36.2
+70	83.7	+40.8	78.6	+44.3	71.9	+46.3	64.5	+46.7	57.3	+45.4
+60	95.0	+46.6	87.5	+52.3	76.3	+55.9	62.9	+56.7	50.3	+54.4
+50	108.6	+51.1	100.1	+59.4	83.6	+65.3	60.1	+66.6	39.5	+62.7
+40	124.5	+53.6	118.4	+64.7	98.5	+73.9	53.6	+76.4	21.3	+69.5
+30	141.4	+53.9	142.3	+66.9	135.7	+79.7	20.3	+85.3	351.7	+73.1
+20	157.7	+51.8	166.7	+65.1	187.8	+77.8	274.9	+82.3	319.0	+71.4
+10	171.9	+47.8	185.8	+60.2	212.4	+70.2	259.5	+72.8	296.7	+65.5
0	183.7	+42.3	199.0	+53.3	222.9	+61.1	255.0	+62.9	283.6	+57.6
−10	193.5	+35.7	208.4	+45.3	228.6	+51.6	252.8	+53.0	275.4	+48.9
−20	201.7	+28.5	215.3	+36.8	232.3	+42.0	251.4	+43.0	269.7	+39.7
−30	208.9	+20.9	220.9	+27.9	235.0	+32.2	250.4	+33.1	265.4	+30.4
−40	215.3	+13.0	225.5	+18.9	237.2	+22.4	249.7	+23.1	261.8	+20.9
−50	221.3	+ 5.0	229.7	+ 9.8	239.2	+12.6	249.0	+13.1	258.7	+11.4
−60	227.2	− 3.1	233.7	+ 0.6	240.9	+ 2.7	248.4	+ 3.1	255.7	+ 1.8
−70	233.2	−11.2	237.7	− 8.6	242.6	− 7.1	247.7	− 6.8	252.8	− 7.7
−80	239.5	−19.1	241.8	−17.7	244.4	−17.0	247.1	−16.8	249.8	−17.3

	15h		16h		17h		18h		19h	
	°	°	°	°	°	°	°	°	°	°
+80	59.6	+34.9	57.4	+33.1	54.8	+31.2	55.3	+28.3	55.3	+25.7
+70	51.4	+42.6	47.1	+38.6	44.7	+33.9	43.9	+28.9	44.5	+23.8
+60	40.9	+49.5	35.3	+43.1	32.7	+35.9	32.5	+28.5	34.1	+21.1
+50	27.4	+55.3	21.9	+46.3	20.3	+36.7	21.3	+27.1	24.1	+17.8
+40	10.3	+59.0	7.4	+47.7	7.9	+36.2	10.4	+24.9	14.4	+14.1
+30	350.6	+60.1	352.6	+47.2	355.8	+34.4	0.0	+22.0	5.1	+ 9.9
+20	331.3	+58.2	338.6	+44.9	344.4	+31.5	350.1	+18.4	356.0	+ 5.6
+10	315.2	+53.9	326.0	+41.0	333.8	+27.7	340.5	+14.3	347.1	+ 1.1
0	302.6	+47.8	314.9	+35.9	324.0	+23.1	331.3	+ 9.9	338.2	− 3.5
−10	292.8	+40.6	305.4	+30.0	314.8	+18.0	322.4	+ 5.2	329.2	− 7.9
−20	285.0	+32.8	296.9	+23.4	306.2	+12.4	313.7	+ 0.4	320.0	−12.2
−30	278.5	+24.6	289.3	+16.4	297.9	+ 6.6	304.9	− 4.4	310.5	−16.1
−40	272.8	+16.1	282.2	+ 9.2	289.9	+ 0.6	296.0	− 9.1	300.6	−19.7
−50	267.6	+ 7.5	275.4	+ 1.8	281.8	− 5.3	286.9	−13.6	290.4	−22.6
−60	262.6	− 1.2	268.7	− 5.6	273.7	−11.2	277.4	−17.7	279.8	−24.9
−70	257.6	− 9.8	261.7	−12.9	265.1	−16.8	267.5	−21.4	268.8	−26.4
−80	252.3	−18.4	254.4	−20.0	256.1	−22.1	257.2	−24.5	257.6	−27.0

	20h		21h		22h		23h		24h	
	°	°	°	°	°	°	°	°	°	°
+80	56.1	+23.2	57.5	+20.9	59.5	+19.1	61.8	+17.7	64.4	+17.0
+70	46.4	+19.0	49.3	+14.7	53.2	+11.2	57.7	+ 8.6	62.6	+ 7.1
+60	37.2	+14.2	41.6	+ 8.1	47.2	+ 3.1	53.7	− 0.6	60.9	− 2.7
+50	28.4	+ 9.2	34.2	+ 1.5	41.3	− 5.0	49.7	− 9.8	59.2	−12.6
+40	19.8	+ 3.9	26.7	− 5.2	35.3	−13.0	45.5	−18.9	57.2	−22.4
+30	11.4	− 1.4	19.1	−11.9	28.9	−20.9	40.9	−27.9	55.0	−32.2
+20	2.9	− 6.8	11.2	−18.3	21.7	−28.5	35.3	−36.8	52.3	−42.0
+10	354.2	−11.9	2.6	−24.3	13.5	−35.7	28.4	−45.3	48.6	−51.6
0	345.2	−16.8	353.3	−29.8	3.7	−42.3	19.0	−53.3	42.9	−61.1
−10	335.7	−21.3	342.9	−34.6	351.9	−47.8	5.8	−60.2	32.4	−70.2
−20	325.7	−25.2	331.4	−38.5	337.7	−51.8	346.7	−65.1	7.8	−77.8
−30	315.1	−28.4	318.8	−41.0	321.4	−53.9	322.3	−66.9	315.7	−79.7
−40	303.9	−30.7	305.5	−42.1	304.5	−53.6	298.4	−64.7	278.5	−73.9
−50	292.3	−32.1	292.0	−41.7	288.6	−51.1	280.1	−59.4	263.6	−65.3
−60	280.5	−32.3	279.1	−39.7	275.0	−46.6	267.5	−52.3	256.3	−55.9
−70	268.7	−31.5	267.1	−36.4	263.7	−40.8	258.6	−44.3	251.9	−46.3
−80	257.3	−29.6	256.2	−32.0	254.3	−34.1	251.8	−35.7	248.8	−36.6

TABLE 760.—Planetary Data

Body	Reciprocals of masses	Mean distance from the sun. km	Sidereal period. Mean days	Inclination of orbit	Mean density. $H_2O = 1$	Gravity at surface
Sun	1	....	....	....	1.42	28.0
Mercury	6000000	58×10^6	87.97	7°.003	5.61	.4
Venus	408000	108 "	244.70	3.393	5.16	.9
Earth*	329390	149 "	365.26	....	5.52	1.00
Mars	3093500	228 "	686.98	1.850	3.95	.4
Jupiter	1047.35	778 "	4332.59	1.308	1.34	2.7
Saturn	3501.6	1426 "	10759.20	2.492	.69	1.2
Uranus	22869	2869 "	30685.93	.773	1.36	1.0
Neptune	19700	4495 "	60187.64	1.778	1.30	1.0
Pluto	....	5900 "	908.85	17.1	....	....
Moon	†81.45	38×10^4	27.32	5.145	3.36	.17

* Earth and moon. † Relative to earth. Inclination of axes: Sun 7°.25; Earth 23°.45; Mars 24°.6; Jupiter 3°.1; Saturn 26°.8; Neptune 27°.2. Others doubtful. Approximate rates of rotation: Sun $25\frac{1}{3}^d$; Moon $27\frac{1}{3}^d$, Mercury 88^d; Venus 225^d; Mars $24^h\ 37^m$; Jupiter $9^h\ 55^m$; Saturn $10^h\ 14^m$. Asteroids (planetoids): Sept. 28, 1931, 1183 had been numbered, inclination Pallas orbit 34° 43′, Hidalgo 43°; e, Albert, 0.54; Hidalgo 0.65. Heaviest meteorite (So. Africa) 50 tons.

TABLE 761.—Satellites of the Solar System

	Mean distance	Sidereal period				Diameter
Earth's: Moon	384,400 km	27^d	7^h	43^m	11.5^s	3476 km
Martian: Phobos	9,380	0	7	39	13.85	15 ?
Deimos	23,460	1	6	17	54.9	8 ?
Jovian: 5th	181,200	0	11	57	22.70	160 ?
1, Io	421,300	1	18	27	33.51	3730
2, Europa	670,500	3	13	13	42.05	3150
3, Ganymede	1,069,300	7	3	42	33.35	5150
4, Callisto	1,881,000	16	16	32	11.21	5180
6th	11,450,000	250.68 d				130 ?
7th	11,730,000	260.06 d				40 ?
8th	23,500,000	738.9 d			*	25 ?
9th	24,100,000	745.0 d			*	25 ?
Saturnian: 7, Mimas	185,700	0	22	37	5.25	650 ?
6, Enceladus	237,900	1	8	53	6.82	800 ?
5, Tethys	294,500	1	21	18	26.14	1300 ?
4, Dione	377,200	2	17	41	9.53	1200 ?
2, Rhea	526,700	4	12	25	12.23	1750 ?
1, Titan	1,220,000	15	22	41	26.82	4200
8, Hyperion	1,480,000	21	6	38	24.0	500 ?
3, Iapetus	3,558,000	79	7	56	24.4	1800 ?
9, Phoebe	12,930,000	550.44 d			*	250 ?
Uranian: 1, Ariel	191,700	2	12	29	20.8	900 ?
2, Umbriel	267,000	4	3	27	36.7	700 ?
3, Titania	438,000	5	16	56	26.7	1700 ?
4, Oberon	586,000	13	11	7	3.5	1500 ?
Neptune's: 1	354,000	5	21	2	38.1*	5000 ?

* Motion retrograde. Notes: Jovian; 1st 4 called Galilean; eccentricity 6, 7, 8, 9; 0.15, 0.21, 0.38, 0.25; masses 1, 2, 3, 4; 1.00, 0.65, 2.10, 0.58 of moon. 6, 7 orbits angle 29° and 28° to Jupiter's; 8, 32° or more properly, 148°. 9, inclination of orbit 156° to planets. Saturnian; Hyperion, mass., 1.86 × moon; Phoebe, eccentricity 0.17; inclination 5°3′ or 174°7′. Uranus; orbits inclined 82°.2 to ecliptic, in that plane revolve backward = 97°.8 to ecliptic and direct motion. Neptune; inclination, 40°. All other satellites are small eccentricity, mass and inclinations. The mass of Saturn's ring < 1/1000000 Saturn's mass.

TABLE 762.—Diameters of the Planets

From critical review by Rabe, Astron. Nach., 234, 154, 1928. Solar parallax taken as 8″.800, earth's radius 6738 km. Order of p.e. ± 0.04 for planets.

Object	At distance	Diameter: apparent	Diameter: km	Diameter: earth = 1	Object	At distance	Diameter: apparent	Diameter: km	Diameter: earth = 1
Mercury	1.000	7″.09	5140	0.403	Saturn: Equat.	9.539	17.44	120600	9.45
Venus	"	17.40	12620	.989	Polar	"	15.77	109000	8.55
Earth	"	17.60	12756	1.000	Outer ring	"	40.29	278500	21.84
Mars: Equat.	"	9.47	6860	.538	Crepe ring	"	20.83	144000	11.29
Polar	"	9.42	6820	.535	Uranus	19.19	3.84	53400	4.19
Jupiter: Equat.	5.203	38.09	143600	11.26	Neptune	30.06	2.28	49700	3.89
Polar	"	35.76	134800	10.57					

TABLE 763.—Planetary and Satellite Distances as Connected by Bode's Law; Later Developments

It is notable that the planetary and satellite distances from their primaries approximately follow Bode's law or some modification thereof. Bode's law: Write a series of fours; to the 2nd add 3; to the 3rd, 3 × 2 or 6; to the 4th, 6 × 2, or 12; etc., doubling the added number each time. Jeans states: "It is more than likely that Bode's law is a mere coincidence" (1929). Penniston (Science, 71, 513, 1930) suggests adding to the square of the integer the integer itself, thus assuming that the terms differ from the square of the integers by a progressively changing amount. See also Caswell, Science, 60, 384, 1929; Armellini, Scientia, 12, 1, 1918; 1, 1922.*

System	Satellite	Relative distance	New law	Bode's law	Caswell's law
Sun	Mercury	3.87	3	4	3.82
"	Venus	7.23	6	7	6.80
"	Earth	10.0	10	10	10.6
"	Mars	15.2	15	16	15.3
"	Ceres	27.7	28	28	27.2
"	Jupiter	52.0	55	52	51.4
"	Saturn	95.3	91	100	95.6
"	Uranus	191.0	190	196	187.0
"	Neptune	300.0	300	. . .	310.0
"	"Pluto"	. . .	406	388	408.0
		. . .	435	388	435.0
Mars	Phobos	1.00	1	. . .	1.70?
"	Deimos	3.22	3	4	3.82
Jupiter	V	2.71	3	4	3.82
"	I	6.27	6	7	6.80
"	II	10.0	10	10	10.6
"	III	15.8	15	16	15.3
"	IV	27.9	28	28	27.2
"	VI	169.4	171	. . .	170.0
"	VII	173.0	171	196	170.0
"	VIII	348.5	351	. . .	357.0
"	IX	371.0	378	388	382.0

System	Satellite	Relative distance	New law	Bode's law	Caswell's law
Saturn	Mimas	10.0	10	10	10.6
"	Enceladus	12.8	. . .	. . .	. . .
"	Tethys	15.8	15	16	15.3
"	Dione	20.3	21	. .	20.8
"	Rhea	28.0	28	28	27.2
"	Titan	66.0	66	52	61.2
"	Themis	78.1	78	. . .	83.1
"	Hyperion	79.0	78	100	83.1
"	Iapetus	190.0	190	196	187.0
"	Phoebe	698.0	703	772	712.0
Uranus	Ariel	10.0	10	10	10.6
"	Umbriel	14.1	15	16	15.3
"	Titania	22.8	21	. . .	20.8
"	Oberon	30.4	28	28	27.2

* See also Narlicker, Philos. Mag. 12, 67. 1931, with note by Larmor. Sir G. Darwin was inclined to regard Bode's Law a subject for serious discussion. See Turner, Blagg, M. N. R. A. S. 73. 414, 1913. See Pruett, Pop. Astron. 39, 360, 1931.

TABLE 764.—Albedos

The albedo, according to Bond, is defined as follows: "Let a sphere *S* be exposed to parallel light. Then its albedo is the ratio of the whole amount reflected from *S* to the whole amount of light incident on it." In the following table, m = the stellar magnitude at mean opposition; g = magnitude it would have at full phase and unit distance from earth and sun; σ = assumed mean semi-diameter at unit distance; p = ratio of observed brightness at full phase to that of a flat disk of same size and same position, illuminated and viewed normally and reflecting all the incident light according to Lambert's law; q depends on law of variation of light with phase; albedo = pq. Russell, Astrophys. Journ., 43, 173, 1916.

Albedo of the earth: A reduction of Very's observations by Russell gives 0.45 in close agreement with the recent value of Aldrich of 0.43 (see Aldrich, Smithsonian Misc. Coll., vol. 69, no. 10, 1919).

Object	m	g	σ	p	q	Visual albedo	Color index	Photographic albedo
Moon	−12.55	+0.40	2.40″	0.105	0.694	0.073	+1.18	0.051
Mercury	−2.04	− .88	3.45	.164	.42	.069	. . . .	. . . .
"	−2.12	− .06	3.45	.077	.72	.055	. . . .	. . . .
Venus	−4.77	−4.06	8.55	.492	1.20	.59	+ .78	.60
Mars	−1.85	−1.36	4.67	.139	1.11	.154	+1.38	.090
Jupiter	−2.29	−8.09	95.23	.375	1.5:	.56:	+ .50	.73:
Saturn	+ .89	−8.67	77.95	.420	1.5:	.63:	+1.12	.47:
Uranus	+5.74	−6.98	36.0	.42	1.5:	.63:		. . . .
Neptune	+7.65	−7.06	34.5	.49	1.5:	.73:		. . . .

TABLE 765.—Equation of Time

The equation of time when + is to be added to the apparent solar time to give mean time. When the place is not on a standard meridian (75th, etc.) its difference in longitude in time from that meridian must be subtracted when east, added when west to get standard time (75th meridian time, etc.). The equation varies from year to year cyclically, and the figure following the ± sign gives a rough idea of this variation.

	Min. Sec.		Min. Sec.		Min. Sec.		Min. Sec.
Jan. 1	+ 3 26 ± 14	Apr. 1	+4 2 ± 7	July 1	+3 31 ± 5	Oct. 1	−10 12 ± 8
15	+ 9 25 ± 9	15	+0 8 ± 5	15	+5 42 ± 3	15	−14 5 ± 6
Feb. 1	+13 42 ± 4	May 1	−2 54 ± 3	Aug. 1	+6 9 ± 3	Nov. 1	−16 19 ± 2
15	+14 20 ± 2	15	−3 49 ± 1	15	+4 24 ± 5	15	−15 22 ± 4
Mar. 1	+12 34 ± 4	June 1	−2 28 ± 3	Sept. 1	+0 2 ± 7	Dec. 1	−10 58 ± 8
15	+ 9 9 ± 6	15	+0 8 ± 4	15	−4 41 ± 9	15	− 4 53 ± 10

SOLAR RADIATION

TABLE 766.—The Solar Constant

Solar constant (amount of energy falling at normal incidence on one square centimeter per minute on body at earth's mean distance) = 1.932 calories = mean 696 determinations 1902—12. Apparently subject to variations, usually within the range of 7 per cent, and occurring irregularly in periods of a week or ten days.

Computed effective temperature of the sun: from form of black-body curves, 6000° to 7000° Absolute; from λmax. = 2930 and max. = 0.470μ, 6230°; from total radiation, $J = 76.8 \times 10^{-12} \times T^4$, 5830°.

TABLE 767.—Solar spectrum energy (arbitrary units) and its transmission by the earth's atmosphere.

Values computed from $e_m = e_0 a^m$, where e_m is the intensity of solar energy after transmission through a mass of air m; m is unity when the sun is in the zenith, and approximately = sec. zenith distance for other positions (see table 778); e_0 = the energy which would have been observed had there been no absorbing atmosphere; a is the fractional amount observed when the sun is in the zenith.

Wave length μ	Transmission coefficients, a: Washington	Mount Wilson	Mount Whitney	One mile nearest earth	Intensity Solar Energy, Arbitrary Units: m = 0	Mount Whitney† m = 1	Mount Wilson (altitude 1675 m) m = 1	2	4	6	Washington (sea-level) m = 1	2	3	4	6
0.30	—	(.460)	(.550)	—	54	30	25	11	2	1	—	—	—	—	—
.32	—	.520	.615	—	111	68	58	30	8	2	—	—	—	—	—
.34	—	.580	.692	—	232	160	135	78	26	9	—	—	—	—	—
.36	—	.635	.741	—	302	224	192	122	49	20	—	—	—	—	—
.38	(.380)	.676	.784	.562	354	278	239	162	74	34	134	51	19	7	3
.40	.560	.729	.800	.768	414	335	302	220	117	62	232	130	73	41	13
.46	.690	.832	.887	.829	618	548	514	428	296	205	426	294	203	140	67
.50	.733	.862	.919	.850	606	557	522	450	334	248	441	323	237	174	94
.60	.779	.900	.940	.866	504	474	454	409	331	268	393	306	238	185	112
.70	.858	.950	.964	.903	364	351	346	329	297	268	312	268	230	197	145
.80	.886	.970	.976	.915	266	260	258	250	235	221	236	209	185	164	145
1.00	.922	.980	.975	.941	166	162	163	160	154	147	153	141	130	120	102
1.50	.938	.976*	.965	.961	63	61	61*	60*	57*	55*	59	55	52	49	43
2.00	.912	.970*	.932	.940	25	23	24*	23*	21*	19*	23	21	19	17	14

Transmission coefficients are for period when there was apparently no volcanic dust in the air.

* Possibly too high because of increased humidity towards noon. † Altitude 4420 m.

TABLE 768.—The amount of Solar Radiation in different sections of the spectrum, ultra-violet, visual infra-red. Calories

Wave length. μ to μ	Mount Whitney. m = 0	m = 1	2	3	4	Mount Wilson. m = 1	2	3	4	Washington. m = 1	2	3	4
0.00 to 0.45	.31	.25	.19	.16	.13	.23	.16	.12	.09	.13	.06	.04	.02
0.45 to 0.70	.71	.67	.62	.58	.54	.65	.57	.51	.45	.53	.40	.30	.24
0.70 to ∞	.91	.87	.85	.82	.80	.69	.68	.66	.63	.69	.62	.57	.53
0.00 to ∞	1.93	1.78	1.66	1.56	1.47	1.57	1.42	1.28	1.17	1.35	1.08	.90	.79

TABLE 769.—Distribution of intensity (Radiation) over the Solar Disk

(These observations extend over only a small portion of a sun-spot cycle.)

Wave length.	μ 0.323	μ 0.386	μ 0.433	μ 0.456	μ 0.481	μ 0.501	μ 0.534	μ 0.604	μ 0.670	μ 0.699	μ 0.866	μ 1.031	μ 1.225	μ 1.655	μ 2.097
Fraction Radius. 0.00	144	338	456	515	511	489	463	399	333	307	174	111	77.6	39.5	14.0
0.40	128	312	423	486	483	463	440	382	320	295	169	108	75.7	38.9	13.8
0.55	120	289	395	455	456	437	417	365	308	284	163	105.5	73.8	38.2	13.6
0.65	112	267	368	428	430	414	396	348	295	273	159	103	72.2	37.6	13.4
0.75	99	240	333	390	394	380	366	326	281	258	152	99	69.8	36.7	13.1
0.825	86	214	296	351	358	347	337	304	262	243	145	94.5	67.1	35.7	12.8
0.875	76	188	266	317	324	323	312	284	247	229	138	90.5	64.7	34.7	12.5
0.92	64	163	233	277	290	286	281	259	227	212	130	86	61.6	33.6	12.2
0.95	49	141	205	242	255	254	254	237	210	195	122	81	58.7	32.3	11.7

Taken from vols. II and III and unpublished data of the Astrophysical Observatory of the Smithsonian Institution. Schwartzchild and Villiger: Astrophysical Journal, 23, 1906.

TABLE 770.—The Solar Constant,* Decade Means (See Tables 771 and 772)

Decade	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
Jan. 1	.....	1.943	1.968	1.956	1.924	1.946	1.937	1.945	1.944	1.939	1.941	1.925
2	.....	1.948	1.967	1.953	1.946	.....	1.943	1.939	1.943	1.938	1.931	1.941
3	.....	1.938	1.959	.....	1.952	.....	1.944	1.947	1.933	1.931	1.942	1.939
Feb. 1	.....	1.962	1.958	.....	1.911	1.934	1.938	.....	1.938	1.936	1.947	1.937
2	.....	1.951	1.954	1.952	1.947	1.951	1.943	1.951	1.939	1.946	1.941	1.925
3	.....	1.930	1.956	1.958	1.948	1.923	1.938	1.938	1.929	.....	1.934	1.925
Mar. 1	.....	1.950	1.959	1.954	1.949	1.929	1.947	1.941	1.941	.....	1.950	1.932
2	.....	1.942	1.948	1.940	1.939	1.936	1.944	1.936	1.948	1.944	1.945	1.931
3	.....	1.931	1.932	.....	1.932	1.931	1.942	1.941	1.932	1.941	1.945	1.932
Apr. 1	.....	1.943	1.948	1.951	1.930	1.934	1.942	1.945	1.927	1.941	1.946	1.932
2	.....	1.957	1.956	1.941	1.937	1.928	1.948	1.950	1.937	1.945	1.940	1.942
3	.....	1.961	1.952	1.934	1.925	1.934	1.947	1.946	1.939	1.945	1.940	1.938
May 1	.....	1.953	1.950	1.946	1.924	1.934	1.944	1.946	1.937	1.947	1.943	1.936
2	.....	1.921	1.961	1.939	1.925	1.935	1.948	1.950	1.938	1.944	1.951	1.941
3	.....	1.945	1.950	1.941	.....	1.937	1.950	1.954	1.942	1.944	1.949	1.937
June 1	.....	1.957	1.943	1.933	1.910	1.918	1.957	1.943	1.939	1.950	1.947	1.938
2	.....	1.938	1.934	1.936	1.913	1.934	1.956	1.943	1.946	1.943	1.948	1.932
3	.....	1.962	1.938	1.945	1.920	1.933	1.953	1.948	1.945	1.945	1.951	1.932
July 1	.....	1.951	1.945	1.960	1.904	1.934	1.946	1.952	1.942	1.949	1.943	1.935
2	.....	1.961	1.940	1.957	1.913	1.928	1.951	1.954	1.949	1.942	1.942	1.931
3	1.921	1.950	1.951	1.953	1.918	1.944	1.942	1.947	1.944	1.946	1.940	1.935
Aug. 1	1.955	1.961	1.930	1.944	1.919	1.942	1.950	1.949	1.945	1.942	1.943	1.931
2	1.945	1.942	1.927	.....	1.916	1.940	1.940	1.941	1.942	1.941	1.937	1.932
3	1.959	1.955	1.932	.....	1.921	1.941	1.933	1.942	1.942	1.941	1.932	1.930
Sept. 1	1.942	1.938	1.951	.....	.....	1.948	1.941	1.956	1.942	1.940	.....	1.926
2	1.946	1.942	1.944	.....	1.931	1.947	1.950	1.946	1.940	1.942	1.938	1.928
3	1.944	1.937	1.944	1.969	1.916	1.945	1.946	1.950	1.943	1.950	1.921	1.929
Oct. 1	1.951	1.947	1.942	1.959	1.926	1.942	1.953	1.942	1.938	1.945	1.930	1.928
2	1.930	1.949	1.950	1.969	1.929	1.944	1.949	1.949	1.937	1.944	1.935	1.934
3	1.933	1.960	1.943	1.966	.....	1.940	1.948	1.946	1.929	1.943	1.927	1.926
Nov. 1	1.928	1.958	1.951	1.953	1.929	1.935	1.948	1.944	1.931	1.945	1.924	1.932
2	1.945	1.951	1.946	1.949	1.935	1.945	1.951	1.948	1.926	1.943	1.932	1.936
3	1.947	1.948	1.945	1.952	1.919	1.945	1.945	1.944	1.930	1.944	1.930	1.939
Dec. 1	1.962	1.944	1.957	1.956	1.912	1.942	1.942	1.944	1.935	1.949	1.930	1.941
2	1.969	1.949	1.957	1.937	1.916	1.942	1.947	1.945	1.931	1.935	1.924	1.939
3	1.960	1.958	1.956	.....	1.912	1.921	1.939	1.946	1.935	1.939	1.927	1.940

TABLE 771.—The Solar Constant, Monthly and Yearly Means

Month	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
Jan.	.....	1.943	1.964	1.955	1.948	1.946	1.942	1.943	1.941	1.938	1.940	1.938
Feb.	.....	1.949	1.956	1.956	1.943	1.930	1.939	1.943	1.938	1.943	1.943	1.929
Mar.	.....	1.941	1.945	1.949	1.938	1.932	1.945	1.939	1.939	1.942	1.946	1.931
Apr.	.....	1.953	1.952	1.944	1.931	1.932	1.946	1.947	1.934	1.944	1.942	1.937
May	.....	1.940	1.953	1.943	1.925	1.936	1.948	1.950	1.939	1.945	1.947	1.938
June	.....	1.955	1.939	1.939	1.914	1.928	1.956	1.945	1.944	1.946	1.948	1.934
July	.....	1.954	1.945	1.956	1.912	1.936	1.946	1.951	1.944	1.945	1.942	1.933
Aug.	1.954	1.953	1.930	1.944	1.919	1.941	1.940	1.945	1.944	1.941	1.937	1.931
Sept.	1.944	1.939	1.947	1.969	1.923	1.947	1.946	1.950	1.942	1.944	1.927	1.928
Oct.	1.939	1.953	1.944	1.962	1.927	1.942	1.949	1.946	1.934	1.944	1.930	1.929
Nov.	1.941	1.953	1.948	1.951	1.929	1.942	1.948	1.946	1.929	1.944	1.929	1.936
Dec.	1.962	1.950	1.957	1.953	1.915	1.933	1.942	1.945	1.932	1.942	1.926	1.940
Yearly mean	.....	1.949	1.948	1.952	1.927	1.937	1.946	1.946	1.938	1.943	1.938	1.934

* In calories/cm²/min. at earth's mean distance from sun (Smithsonian Astrophysical Observatory).

TABLE 772.—The Solar Constant, 1930, 1931

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1930 Decades	1	1.938	1.933	1.940	1.941	1.945	1.949	1.945	1.946	1.942	1.939	1.943	1.945	1.942
	2	1.937	1.939	1.937	1.938	1.948	1.944	1.949	1.947	1.929	1.941	1.943	1.948	1.942
	3	1.929	1.942	1.940	1.941	1.942	1.941	1.947	1.943	1.939	1.939	1.949	1.945	1.941
Means		1.936	1.938	1.939	1.940	1.944	1.943	1.947	1.945	1.937	1.940	1.944	1.947	1.942
1931 Decades	1	1.944	1.942	1.932	1.948	1.936	1.943	1.954	1.948	1.946	1.939	1.943	1.945	1.943
	2	1.944	1.945	1.945	1.948	1.948	1.948	1.949	1.948	1.948	1.941	1.943	1.948	1.946
	3	.....	1.941	1.948	1.936	1.947	1.946	1.943	1.943	1.945	1.939	1.949	1.945	1.944
Means		1.944	1.943	1.944	1.945	1.944	1.946	1.949	1.946	1.946	1.940	1.944	1.947	1.945

TABLE 773.—Wolf's Observed Sun-Spot Numbers. Annual Means

Sun-spot number = k(10 × number of groups and single spots observed + total number of spots in groups and single spots). k depends on condition of observation and telescope, equaling unity for Wolf with 3-in. telescope and power of 64. Wolf's numbers are closely proportional to spotted area on sun; 100 corresponds to about 1/500 of visible disk covered (umbras and penumbras). Periodicity: mean 11.13, extremes, 7.3 and 17.1 years. Terr. Magn. 30, 83, 1925, monthly means 1749–1924. See A. Wolfer in Astronomische Mitteilungen and Zeitschrift für Meteorologie, daily and monthly values. See also Bull. for Character Figures of Solar Phenomena, Int. Astron. Union, Eidgen, Zurich, for spots and other solar phenomena. Also, Terr. Magn. and Atm. Elec., 33, 223, 1928, for central spots, 1917 to 1927.

Year	0	1	2	3	4	5	6	7	8	9
1750	83	48	48	31	12	*10*	10	32	48	54
1760	63	**86**	61	45	36	21	*11*	38	70	**106**
1770	101	82	66	35	31	*7*	20	92	**154**	126
1780	85	68	38	23	*10*	24	83	**132**	131	118
1790	90	67	60	47	41	21	16	6	*4*	7
1800	14	34	45	43	**48**	42	28	10	8	2
1810	*0*	1	5	12	14	35	**46**	41	30	24
1820	16	7	4	*2*	8	17	36	50	62	67
1830	**71**	48	28	*8*	13	57	122	**138**	103	86
1840	63	37	24	*11*	15	40	62	98	**124**	96
1850	66	64	54	39	21	7	*4*	23	55	94
1860	**96**	77	59	44	47	30	16	*7*	37	74
1870	**139**	111	102	66	45	17	11	12	*3*	6
1880	32	54	60	**64**	64	52	25	13	7	*6*
1890	7	36	73	**85**	78	64	42	26	27	12
1900	10	*3*	5	24	42	**63**	54	62	48	44
1910	19	6	4	*1*	10	47	57	**104**	81	64
1920	38	26	14	6	17	44	64	69	78	65
1930	36	21	11	..	..	..	..	..	..	..

NOTE—The sun's apparent magnitude is −26.5, sending the earth 90,000,000,000 times as much light as the star Aldebaran. Its absolute magnitude is + 4.8.

Ratio of total radiation of sun to that of moon about 100,000 to 1 } Langley.
" " " light " " " " " " " 400,000 to 1 }

TABLE 774.—Duration of Sunshine

Declination of sun:	−23° 27′	−15°	−10°	−5°	0°	+5°	+10°	+15°	+20°	+23° 27′
Approx. date:	Dec. 22	Feb. 9 Nov. 3	Feb. 23 Oct. 19	Mar. 8 Oct. 6	Mar. 21 Sept. 23	Sept. 10 Apr. 3	Apr. 16 Aug. 28	May 1 Aug. 13	May 20 Jan. 24	June 21
Latitude	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
0°	12 07	12 07	12 07	12 07	12 07	12 07	12 07	12 07	12 07	12 07
10°	11 32	11 45	11 53	12 00	12 07	12 14	12 21	12 29	12 36	12 43
20°	10 55	11 22	11 38	11 53	12 07	12 22	12 37	12 52	13 08	13 20
30°	10 13	10 57	11 21	11 44	12 08	12 31	12 55	13 19	13 46	14 05
40°	9 19	10 25	11 01	11 35	12 09	12 43	13 17	13 53	14 32	15 01
50°	8 04	9 43	10 34	11 23	12 10	12 58	13 48	14 40	15 38	16 23
55°	7 09	9 12	10 15	11 14	12 12	13 09	14 09	15 13	16 26	17 23
60°	5 52	8 34	9 52	11 04	12 13	13 23	14 36	15 57	17 31	18 52
65°	3 34	7 39	9 19	10 50	12 16	13 43	15 15	17 01	19 19	22 03
70°	..	6 10	8 31	10 29	12 19	14 11	16 15	18 50	..	..
75°	..	2 37	7 04	9 55	12 26	15 00	18 05	..	..	..
80°	..	..	3 10	8 46	12 38	16 44	..	..	..	..

For more extensive table, see Smithsonian Meteorological Tables

ATMOSPHERIC TRANSPARENCY AND SOLAR DATA

TABLE 775.—Transmission of Radiation Through Moist and Dry Air

This table gives the wave-length, λ; a the transmission of radiation by dry air above Mount Wilson (altitude = 1730 m. barometer, 620 mm.) for a body in the zenith; finally a correction factor, a_w, due to such a quantity of aqueous vapor in the air that if condensed it would form a layer 1 cm. thick. Except in the bands of selective absorption due to the air, a agrees very closely with what would be expected from purely molecular scattering. a_w is very much smaller than would be correspondingly expected, due possibly to the formation of ions by the ultra-violet light from the sun. The transmission varies from day to day. However, values for clear days computed as follows agree within a per cent or two of those observed when the altitude of the place is such that the effect due to dust may be neglected, e. g. for altitudes greater than 1000 meters. If B = the barometric pressure in mm., w, the amount of precipitable water in cm., then $a_B = a^{\frac{B}{620}} a_w^w$. w is best determined spectroscopically (Astrophysical Journal, 35, p. 149, 1912, 37, p. 359, 1913) otherwise by formula derived from Hann, $w = 2.3 e_w 10^{-\frac{h}{22000}}$, e_w being the vapor pressure in cm. at the station, h, the altitude in meters. See Table 449 for long-wave transmission.

λ (μ)	.360	.384	.413	.452	.503	.535	.574	.624	.653	.720	.986	1.74
a	(.660)	.713	.783	.840	.885	.898	.905	.929	.938	.970	.986	.990
a_w	.950	.960	.965	.967	.977	.980	.974	.978	.985	.988	.990	.990

Fowle, Astrophysical Journal, 38, 1913.

TABLE 776.—Brightness of (radiation from) Sky at Mt. Wilson (1730 m.) and Flint Island (sea-level)

Zenith dist. of zone		0–15°	15–35°	35–50°	50–60°	60–70°	70–80°	80–90°	–	Sun
$10^8 \times$ mean ratio sky/sun	Mt. Wilson	1500*	400	520	610	660	700	720	–	–
" "	Flint Island	115	122	128	150	185	210	460	–	–
Ditto × area of zone	Mt Wilson	51.0	58.8	91.5	87.2	104.3	117.6	125.3	–	636
" " "	Flint Island	3.9	17.9	22.5	21.4	29.2	35.3	80.0	–	210
Altitude of sun		–	–	5°	15°	25°	35°	47½°	65°	82½°
Sun's brightness, cal. per cm.² per min.		–	–	.533	.900	1.233	1.358	1.413	1.496	1.521
Ditto on horizontal surface		–	–	.046	.233	.524	.780	1.041	1.355	1.507
Mean brightness on normal surface sky × 10^8/sun		–	–	423	403	.385	365	346	326	310
Total sky radiation on horizontal cal. per cm.² per m.		–	–	.056	.110	.162	.189	.205	.225	.240
Total sun + sky, ditto		–	–	.102	.343	.686	.969	1.246	1.581	1.747

* Includes allowance for bright region near sun. For the dates upon which the observation of the upper portion of table were taken, the mean ratios of total radiation sky/sun, for equal angular areas, at normal incidence, at the island and on the mountain, respectively, were 636×10^{-8} and 210×10^{-8}, on a horizontal surface, 305×10^{-8} and 77×10^{-8}; for the whole sky, at normal incidence, 0.57 and 0.20; on a horizontal surface 0.27 and 0.07. Annals of the Astrophysical Observatory of the Smithsonian Institution, vols. II and III, and unpublished researches (Abbot).

TABLE 777.—Relative Distribution in Normal Spectrum of Sunlight and Sky-light at Mount Wilson

Zenith distance about 50°.

	μ	μ	μ	μ	μ	μ	C	D	b	F
Place in Spectrum	0.422	0.457	0.491	0.566	0.614	0.660				
Intensity Sunlight	186	232	227	211	191	166				
Intensity Sky-light	1194	986	701	395	231	174				
Ratio at Mt. Wilson	642	425	309	187	121	105	102	143	246	316
Ratio computed by Rayleigh	–	–	–	–	–	–	102	164	258	328
Ratio observed by Rayleigh	–	–	–	–	–	–	102	168	291	369

TABLE 778.—Air Masses

See Table 767 for definition. Besides values derived from the pure secant formula, the table contains those derived from various other more complex formula, taking into account the curvature of the earth, refraction, etc. The most recent is that of Bemporad.

Zenith Dist.	0°	20°	40°	60°	70°	75°	80°	85°	88°
Secant	1.00	1.064	1.305	2.000	2.924	3.864	5.76	11.47	28.7
Forbes	1.00	1.065	1.306	1.995	2.902	3.809	5.57	10.22	18.9
Bouguer	1.00	1.064	1.305	1.990	2.900	3.805	5.56	10.20	19.0
Laplace	1.00	–	–	1.993	2.899	–	5.56	10.20	18.8
Bemporad	1.00	–	–	1.995	2.904	–	5.60	10.39	19.8

The Laplace and Bemporad values, Lindholm, Nova Acta R. Soc. Upsal. 3, 1913: the others, Radau's Actinometric, 1877.

TABLE 779
SOLAR DATA
58 Elements Known in the Sun's Atmosphere

Taken, with additions and corrections, from St. John's Revision of Rowland. Papers of Mount Wilson Observatory, vol. 3 (Carnegie Inst. Publ. 396, 1928).

At. no., element		Atomic state								Molecular state	
		Reversing layer.					Chromosphere or spots.‡			Band lines	
		No. lines	Max. int.	Ele. +	No. lines	Max. int	No. lines	Max. int.	Locus	Source	Locus
1	H	6	40				30	100	Chr	OH; NH; CH MgH; CaH	D, S ‖ Spots
2	*He	1	0	†			30	40	Chr		
3	Li						1	4	Spots		
4	Be	2	−3	Be+	3	1					
5	B									BO	Spots
6	C	9	0							CN; CH; (C−)	D, S
7	N	1	−2							NH; CN	D, S
8	O	5	2							OH; TiO §	Spots
11	Na	22	30								
12	Mg	25	30	Mg+	2	0				MgH	Spots
13	Al	8	20	Al+?	1	−2					
14	Si	22	12	Si+	5	2					
16	S?	3	−1								
19	K	5	0								
20	Ca	115	15	Ca+	12	200				CaH	Spots
21	Sc	74	2	Sc+	71	5	5	2	Spots		
22	Ti	769	7	Ti+	300	12	16	3	Spots	TiO §	Spots
23	V	470	4	V+	140	5	8	1	Spots		
24	Cr	859	5	Cr+	168	5	1	−1	Spots		
25	Mn	440	7	Mn+	18	6					
26	Fe	3157	40	Fe+	131	6					
27	Co	773	6	Co+	10	0	2	0	Spots		
28	Ni	611	20	Ni+	17	2					
29	Cu	26	10								
30	Zn	10	3								
31	Ga	2	−1								
32	Ge	5	0								
37	Rb						2	1	Spots		
38	Sr	22	−1	Sr+	7	8	4	−1	Spots		
39	Y	47	0	Y+	69	3	4	5	Spots		
40	Zr	126	−1	Zr+	238	2	7	0	Spots		
41	Cb?	12	−2	Cb+	6	−1					
42	Mo	38	−2	Mo+	8	0					
44	Ru	24	0								
45	Rh	20	−2								
46	Pd	21	0								
47	Ag	2	0								
48	Cd	1	−1								
49	In						1	−1	Spots		
50	Sn?	2	−2								
51	Sb	3	−3N								
55	Cs	2	1								
56	Ba			Ba+	9	8					
57	La			La+	100	1					
58	Ce			Ce+	249	0					
59	Pr			Pr+?	18	−1					
60	Nd			Nd+	107	0					
62	Sa			Sa+	67	−1					
63	Eu			Eu+?	5	1					
64	Gd			Gd+?	15	0					
66	Dy			Dy+	12	0					
68	Er			Er+?	2	−1					
70	Yb			Yb+?	2	−1?					
72	Hf			Hf+	12	−1					
74	W	6	−2								
78	Pt	3	1								
81	Tl?	2	−2								
82	Pb	6	−2								

* λ 5875.618 He often present (absorption) over disturbed regions of disk. † λ 4685.81 He+1N, present in chromosphere. ‡ Only in chromosphere or spots. § Possibly TiO_2 in red. ‖ Present in disk and spots.

TABLE 780
SOLAR DATA
Quantitative Estimates of Composition of Solar Atmosphere

(Taken from Russell, Astrophys. Journ., 70, 11, 1929.)

In the *chromosphere* a deep layer of gases is held up by radiation pressure. The (gas) pressure, p, and density, d, increase slowly downwards as gravity gradually balances the radiation pressure. At the base p may be about 10^{-7} atmosphere. At lower levels is the *reversing layer* in which gravity is dominant, p increases rapidly, and temperature remains nearly constant at 5000° K., as long as the gases are transparent. When $p < 0.01$ atm. general absorption by electron collisions make gas hazy. Opacity gains greatly with p, passes rapidly to the *photosphere*. When opacity important, temperature rises (radiative equilibrium, Schwarzschild, Eddington). Observed photospheric temperature = mean value of the radiating layers (Russell, Stewart, Astrophys. Journ. 59, 197, 1924).

The presence and absence of lines of different elements depends on the excitation potential. Almost all the elements for which this is less than 5 volts appear. There are very few other lines except the strong ones of H. The level of ionization in solar atmosphere is such that those of 8.3 volts are 50% ionized.

Na, Mg, Si, K, Ca, and Fe are 95% of the whole mass. Number of metallic atoms above cm² of surface = 8×10^{20}. 80% are ionized. Mean atomic weight = 32, total mass 42 mg/cm². Even atomic weights 10 times as abundant as odd. Heavy metals (Ba onwards) little less abundant than those beyond Sr. Hypothesis that heavy metals sink below photosphere thus not confirmed. Metals Na-Zn far most common. Most elements not appearing in the table would hardly be expected to show spectral lines under solar conditions.

Nonmetal abundance difficult to estimate. O is as abundant by weight as all metals together. Atmosphere = 60 H by vol., 2 He, 2 O, 1 of metallic vapors, 0.8, free electrons. Temperature of reversing layer = 5600° K.; pressure at its base 0.005 atm.

In the following table, S_o = whole no. neutral atom/cm²; S_i, no. ionized; T, total no. both stages of ionization; Q, total mass/cm² = $T \times$ at. wt. :, ::, indicate less accuracy; ?, origin doubtful.

El.	log S_o	log S_i	log T	log Q	El.	log S_o	log S_i	log T	log Q	El.	log S_o	log S_i	log T	log Q
H	11.5::	5.7::	11.5::	11.5::	Cu	4.3	4.9	5.0	6.8	Ce	....	2.4	2.4	4.6
Li	−0.9	2.0:	2.0:	2.8:	Zn	4.9	3.8	4.9	6.7	Pr	....	0.6:	0.6:	2.8:
Be	1.8	0.8	1.8	2.8	Ga	0.2:	2.0:	2.0:	3.8:	Nd	....	2.0	2.0	4.2
C	7.4	4.4:	7.4:	8.5:	Ge	2.5	2.8	3.0	4.9	Sa	....	1.5	1.5	3.7
N	7.6?	1.8?	7.6?	8.7?	As	0.6	−0.7?	0.6?	2.5	Eu	....	1.4:	1.4:	3.6:
O	9.0	3.3:	9.0:	10.2:	Rb	−2.5:	1.7:	1.7:	3.6:	Gd	....	1.1:	1.1:	3.3:
Na	4.0	7.2	7.2	8.6	Sr	0.6	3.3	3.3	5.2	Dy	....	1.6:	1.6:	3.8:
Mg	7.0	7.7	7.8	9.2	Vt	0.8	2.6	2.6	4.5	Er	....	0.1:	0.1:	2.3:
Al	4.6	6.4	6.4	7.8	Zr	0.9	2.5	2.5	4.5	Hf	....	0.4	0.4	2.6
Si	7.0	7.0	7.3	8.8	Cb	−0.2:	1.0:	1.0:	3.0:	W	−0.1	−0.1	0.2	2.5
S	5.7:	3.4:	5.7:	7.2:	Mo	0.5	1.4	1.4	1.4	Ir	−0.5?	−0.5?	−0.2?	2.1?
K	2.8:	6.8:	6.8:	8.4:	Ru	1.0	1.6	1.7	3.7	Pt	1.5	1.0	1.6	3.9
Ca	4.6	6.7	6.7	8.3	Rh	−0.3	0.5	0.5	2.5	Tl	−0.8?	1.4?	1.4?	3.7?
Sc	1.9	3.6	3.6	5.3	Pd	0.6	0.9	1.1	3.1	Pb	0.2	1.2	1.2	3.5
Ti	3.6	5.2	5.2	6.9	Ag	0.0	1.0	1.0	3.0					
V	1.9	5.0	5.0	6.7	Cd	2.1:	1.6:	2.2:	4.2:	CN	3.2	....	3.2	4.6
Cr	4.4	5.7	5.7	7.4	In	−2.0:	0.0:	0.0:	2.1:	C_2	1.3	....	1.3	2.7
Mn	5.1	5.8	5.9	7.6	Sn	0.3?	1.2?	1.2?	3.3?	CH	3.0	....	3.0	4.1
Fe	6.7	7.1	7.2	9.0	Sb	0.4:	0.7:	0.8:	2.9:	NH	2.1	....	2.1	3.3
Co	5.1	5.4	5.6	7.4	Ba	−0.2	3.3	3.3	5.4	OH	3.0	....	3.0	4.2
Ni	5.7	5.7	6.0	7.8	La	0.7	1.8	1.8	3.9	BO	1.4	....	1.4	2.8

Comparison of above values with values of Payne by a very different process show good agreement except for H (Payne 12.9, Russell, 11.5, the latter uncertain) and K, (Payne 5.3, Russell 6.8; the former probably too low).

SOLAR DATA

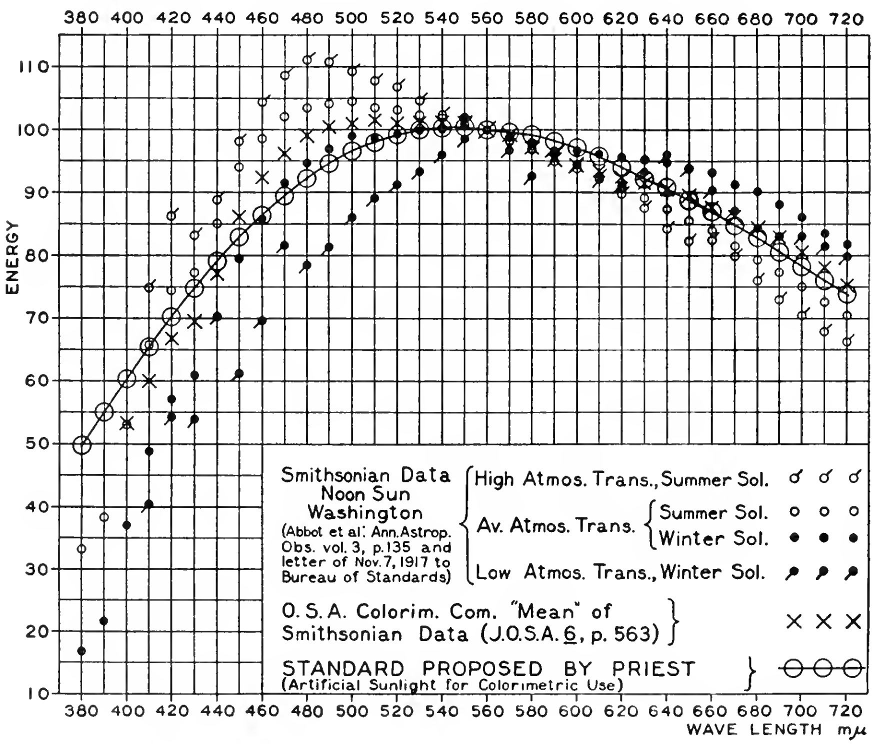
TABLE 781.—Abundance of Elements in Sun, Earth, and Meteorites

(Taken from Russell, Astrophys. Journ., 70, 66, 1929.)

El.	Sun	Earth	E—S	Meteorites	M—S	El.	Sun	Earth	E—S	Meteorites	M—S
Na	8.6	8.7	+ 0.1	7.8	− 0.8	Ni	7.8	6.8	− 1.0	8.2	+ 0.4
Mg	9.2	8.6	− 0.6	9.1	− 0.1	Cu	6.8	6.3	− 0.5	6.2	− 0.6
Al	7.8	9.2	+ 1.4	8.2	+ 0.4	Zn	6.7	5.9	− 0.8	...	...
Si	8.8	9.7	+ 0.9	9.3	+ 0.5						
K	8.4 :[1]	8.7	+ 0.3	7.2	− 1.2	H	11.5 :	8.3	− 3.2	6.9	− 4.6
Ca	8.3	8.8	+ 0.5	8.1	− 0.2	C	8.5 :	7.4	− 1.1 :	7.2	− 1.3
Sc	5.3	3. :	− 2. :	...	...	N	8.7 ?[2]	6.8	− 1.9?	...	...
Ti	6.9	8.1	+ 1.2	7.0	+ 0.1	O	10.2	9.7	− 0.5 :	9.6	− 0.6
V	6.7	6.9	+ 0.2	...	...	F	...	6.8	...	...	...
Cr	7.4	7.1	− 0.3	7.5	+ 0.1	P	...	7.4	...	7.0	...
Mn	7.6	7.3	− 0.3	7.3	− 0.3	S	7.2	7.3	+ 0.1	8.3	+ 1.1
Fe	9.0	9.0	0.0	9.4	+ 0.4	Cl	...	7.7	...	6.9	...
Co	7.4	5.8	− 1.6	7.1	− 0.3						

[1] : indicates less accuracy.
[2] ? indicates doubtful origin.

TABLE 782.—Abbot-Priest Solar Energy Curve (Sea-Level)



STELLAR DATA

TABLE 783.—Constellation Abbreviations (Astron. Union, 1922)

Andromeda	And	Circinus	Cir	Lacerta	Lac	Pisces Austr.	PsA
Antlia	Ant	Columba	Col	Leo	Leo	Puppis	Pup
Apus	Aps	Coma Beren.	Com	Leo Minor	LMi	Pyxis	Pyx
Aquarius	Aqr	Corona Aust.	CrA	Lepus	Lep	Reticulum	Ret
Aquila	Aql	Corona Bor.	CrB	Libra	Lib	Sagitta	Sge
Ara	Ara	Corvus	Crv	Lupus	Lup	Sagittarius	Sgr
Aries	Ari	Crater	Crt	Lynx	Lyn	Scorpius	Sco
Auriga	Aur	Crux	Cru	Lyra	Lyr	Sculptor	Scl
Boötes	Boo	Cygnus	Cyg	Mensa	Men	Scutum	Sct
Caelum	Cae	Delphinus	Del	Microscopium	Mic	Serpens	Ser
Camelopardalis	Cam	Dorado	Dor	Monoceros	Mon	Sextans	Sex
Cancer	Cnc	Draco	Dra	Musca	Mus	Taurus	Tau
Canes Venatici	CVn	Equuleus	Equ	Norma	Nor	Telescopium	Tel
Canis Major	CMa	Eridanus	Eri	Octans	Oct	Triangulum	Tri
" Minor	CMi	Fornax	For	Ophiuchus	Oph	" Austr.	TrA
Capricornus	Cap	Gemini	Gem	Orion	Ori	Tucana	Tuc
Carina	Car	Grus	Gru	Pavo	Pav	Ursa Major	UMa
Cassiopeia	Cas	Hercules	Her	Pegasus	Peg	" Minor	UMi
Centaurus	Cen	Horologium	Hor	Perseus	Per	Vela	Vel
Cepheus	Cep	Hydra	Hya	Phoenix	Phe	Virgo	Vir
Cetus	Cet	Hydrus	Hyi	Pictor	Pic	Volans	Vol
Chamaeleon	Cha	Indus	Ind	Pisces	Psc	Vulpecula	Vul

TABLE 784.—Occurrence and Abundance of Elements in the Stars

(Shapley, 1931. Payne, Stellar atmosphere, 1925. I, II, III, IV denote the occurrence of the neutral, once, twice, and thrice ionized atom. For the sun see Tables 780 and 781.)

At. no., element	State in star	Abundance	At. no., element	State in star	Abundance	At. no., element	State in star	At. no., element	State in star
1 H	I	12.9	18 A	...	...	35 Br	...	52 Te	...
2 He	I II	10.2	19 K	I II	5.3	36 Kr	...	53 I	...
3 Li	I	1.9	20 Ca	I II	6.7	37 Rb	...	54 Xe	...
4 Be	"	...	21 Sc	I II	...	38 Sr	I II	55 Cs	...
5 B	"	...	22 Ti	I II	6.0	39 Y	I II	56 Ba	II†
6 C	I II III	6.4	23 V	I II	4.9	40 Zr	I II*	57 La	II
7 N	II III	...	24 Cr	I II	5.8	41 Cb	...	58 Ce	II
8 O	I II III	8.0	25 Mn	I II	6.5	42 Mo	...	59 Pr	...
9 F	...	...	26 Fe	I II	6.7	43 Ma	...	60 Nd	II
10 Ne	...	...	27 Co	I II	...	44 Ru	...	61 Il	...
11 Na	I	7.1	28 Ni	I II	..	45 Rh	...	62 Sa	...
12 Mg	I II	7.5	29 Cu	I	...	46 Pd	...	63 Eu	II
13 Al	I II III	6.9	30 Zn	I	...	47 Ag	...	64 Gd	...
14 Si	I II III IV	7.5	31 Ga	...	...	48 Cd	I	65 Tb	...
15 P	II ? III	...	32 Ge	...	...	49 In	...	66 Dy	...
16 S	II III	...	33 As	...	...	50 Sn	...	67 Ho	...
17 Cl	...	...	34 Se	...	...	51 Sb	...	68 Er	II ?

Elements of higher atomic number than 68 have not been noted.

* Abundance 3.5. † Abundance, 3.0.

STELLAR SYSTEMS

(See Shapley, Harvard Reprint 68, 1931, Harvard Explorations, Science, 74, 207, 1931.)

The solar neighborhood distance of *50 light-years*, explored chiefly through the motions of nearby stars. A large majority are of less than solar luminosity, most below naked eye visibility. Only 40% of the stars known to be nearer than 16 light-years are brighter than the 6th magnitude. Exploring the solar neighborhood therefore involves a search for telescopic dwarf stars. Any body 1/100 of sun's mass within 1,000 astronomical units (.015 light year) would be detected by its disturbance on Neptune and Uranus even if invisible (Russell). Nearest known star is 4 light-years distant (Proxima centauri, $m = 11$, $M = 15.5$).

Region of brighter stars extending *500 light-years*. The great majority of naked-eye stars lie in this region, though some of unusually high intrinsic luminosity are farther away. It includes probably 500,000 telescopic stars. Studied by proper motions, trigonometric and spectroscopic parallaxes, and photometry.

The local system.—Its diameter is *several thousand light-years*. There is good but not incontrovertible evidence of a localized star cloud in our part of the galaxy. Its population is in the tens or hundreds of millions of stars. Shapley considers it may be comparable in dimensions and composition with Magellanic clouds or a typical spiral nebula. Investigated principally statistically by spectra, magnitudes, and positions, and explored by spectroscopic parallaxes, star counts, and structure of variable stars and galactic clusters.

The Milky Way with a radius much greater than *5000 light-years*. The stars within 5000 light-years of the sun are a trifling part of the galactic system outlined by the globular clusters and Milky Way clouds. The stars are so remote that proper motions and spectroscopic analyses hopelessly fail. Statistical counts are of some help in the nearer parts. But most of our knowledge comes from eclipsing binaries, long-period variables, and Cepheids. The period-luminosity relation for Cepheid variables is the key to practically all distances > a few 1000 light-years.

The Clouds of Magellan, nearly *100,000 light-years* distant, nearest of all external galaxies and the most easily studied. Great advantage; all of its varied manifestations are seen at practically the same distance. These phenomena include gaseous nebulae, star clusters, giant and supergiant stars, some 1500 known Cepheids in the Larger Cloud. In this cloud 750 stars brighter than — 5.0 abs. mag. and over 200,000 brighter than the 0.0 have been estimated. The following gives an indication of the classes of stars measured in and in front of the Larger Cloud and adjacent field.

Class	O	B	A	F	G	K	M
Cloud	8	28	66	153	771	768	385
Field	0	0	10	35	206	172	77
Difference	8	28	56	118	565	596	308

The Super-Galaxies, *1,000,000 to 100,000,000 light-years* distant. Composed of clusters of extra-galactic nebulae. The relative diameters and brightnesses have been determined for some of the super-galaxies. The most conspicuous is the Coma-Virgo cloud A, a stream of several hundred bright spiral, spheroidal, and irregular galaxies, about 10^7 light-years distant; its greatest length about $\frac{1}{2}$ this. One of the richest and most distinct super-galaxies is in Centaurus.

The Meta-Galaxy.—Great irregularity is found in the distribution of the objects exterior to our galaxy—perhaps partly due to obscuring clouds in our system but much attributable to aggregation of galaxies into super-systems and large indefinite streams. We find no evidence that we have approached the limits of a populated universe—no falling off in the number per cubic million light-years. The red-shift in the spectra of distant galaxies may be taken as an observational, relativistic indication of an expanding finite universe, "but so far as the present census of the meta-galaxy goes, the total number of galaxies and the radius of space may both be infinite" (Shapley).

TABLE 786.—Stellar Spectra and Related Characteristics

The spectra of almost all the stars can be arranged in a continuous sequence, the various types connected in a series of imperceptible gradations. With one unimportant exception, the sequence is linear. According to the now generally adopted Harvard system of classification, certain principal types of spectrum are designated by letters—O, B, A, F, G, K, M, R, S, N, P, and Q—and the intermediate types by suffixed numbers. A spectrum halfway between classes B and A is denoted B5, while those differing slightly from Class A in the direction of Class B are called B8 or B9. In Classes M and O the notation Ma, Mb, Mc, etc., is employed. Classes R and N apparently form a side chain branching from the main series near Class K.

The colors of the stars, the degree to which they are concentrated into the region of the sky, including the Milky Way, and the average magnitudes of their peculiar velocities in space, referred to the center of gravity of the naked-eye stars as a whole, all show important correlations with the spectral type. In the case of colors, the correlation is so close as to indicate that both spectrum and color depend almost entirely on the surface temperature of the stars. The correlation in the other two cases, though statistically important, is by no means as close.

Examples of all classes from O to M are found among the bright stars. The brightest star of Class N is of magnitude 5.3; the brightest of Class R, 7.0. About 1% show bright lines.

TABLE 787.—The Harvard Spectrum Classification

Class	Principal spectral lines (dark unless otherwise stated)	Example	Number brighter than 6.25 mag.	Per cent in galactic region	Color index	Effective surface temperature, K.	Mean peculiar velocity, km/sec.
O	Bright H lines, bright spark lines of He, N, O, C...........	γ Velorum	20	100	−0.3	..	..
B	H, He, spark lines of N and O, a few spark lines of metals......	ϵ Orionis	696	82	−0.30	20,000°	6
A	H series very strong, spark lines of metals.	Sirius	1885	66	0.00	11,000°	10
F	H lines fainter. Spark and arc lines of metals	Canopus	720	57	+0.33	7,500°	14
G	Arc lines of metals, spark lines very faint..............	The sun	609	58	+0.70	5,000°	15
K	Arc lines of metals, spectrum faint in violet.............	Arcturus	1719	56	+1.12	4,200°	17
M	Bands of TiO_2, flame and arc lines of metals	Antares	457	54	+1.00	3,100°	17
R	Bands of carbon, flame and arc lines of metals............	B. D. −10° 5057	0	63	+1.7	3,000°	15
S	Bands ZrO_2, metal flame and arc lines; in S_e, bright H and metallic lines of high excitation. Latter are always long period variables....	η_1 Gruis	0	..	..	3,000°?	..
N	Bands of carbon, bright lines, very little violet light....	19 Piscium	8	87	+2.5	2,300°	13
P	Isolated bright lines, gaseous nebulae....	..	..	..	..	..	..
Q	Novae (see Russell, Dugan and Stewart, Astronomy, p. 780).	..	..	..	..	..	..

Compiled mainly from the Harvard Annals. Temperatures based on the work of Wilsing and Scheiner (see also pp. 632-3). Radial velocities from Campbell. Data for classes R and N from Curtis and Rufus. The peculiar velocities are in the radial direction (towards or from the sun). The average velocities in space should be twice as great. The "galactic region" here means the zone between galactic latitudes ± 30°, and including half the area of the heavens. 96% of the stars of known spectra belong to classes A, F, G, K, 99.7% including B and M (Innes, 1919). Henry Draper Catalogue, 9 vols., 1918-24, with later volumes give positions, magnitudes and spectra of more than 225,000 stars. See also Catalogue of Bright Stars. Schlesinger, Yale Univ. Obs., 1930.

TABLE 788.—Values of Log (no. stars)/(sq. degree) Brighter Then Photographic Magnitude, *m*, at Stated Galactic Latitudes

m	+90°	+40°	+20°	+10°	0°	−10°	−20°	−40°	−90°	Ratio nos. successive magnitudes +90°	Ratio nos. successive magnitudes 0°	Ratio nos. successive magnitudes −90°	Ratio nos. at 0° to ± 90° +90°	Ratio nos. at 0° to ± 90° −90°
5.0	8.15	8.24	8.37	8.49	8.77	8.65	8.50	8.25	8.07				4.1	5.0
6.0	8.59	8.72	8.85	8.95	9.22	9.10	8.94	8.71	8.62	2.8	2.8	3.5	4.3	4.0
7.0	9.02	9.18	9.31	9.41	9.64	9.51	9.35	9.16	9.08	2.7	2.6	2.9	4.1	3.6
8.0	9.44	9.62	9.77	9.87	0.09	9.93	9.79	9.60	9.50	2.6	2.8	2.6	4.5	3.9
9.0	9.86	0.05	0.21	0.33	0.55	0.37	0.23	0.04	9.92	2.6	2.9	2.6	4.9	4.3
10.0	0.25	0.47	0.65	0.77	1.02	0.82	0.67	0.47	0.32	2.5	3.0	2.5	5.9	5.0
11.0	0.63	0.87	1.08	1.21	1.49	1.26	1.11	0.89	0.72	2.4	3.0	2.5	7.2	5.9
12.0	1.01	1.26	1.50	1.64	1.95	1.70	1.54	1.29	1.12	2.4	2.9	2.5	8.7	6.8
13.0	1.38	1.63	1.90	2.05	2.39	2.14	1.95	1.68	1.48	2.3	2.8	2.3	10	8.1
14.0	1.70	1.97	2.28	2.45	2.82	2.57	2.34	2.03	1.78	2.1	2.7	2.0	13	11
15.0	1.98	2.30	2.66	2.85	3.22	2.99	2.72	2.34	2.02	1.9	2.5	1.7	17	16
16.0	2.26	2.61	3.02	3.25	3.60	3.39	3.07	2.64	2.26	1.9	2.4	1.7	22	22
17.0	2.53	2.90	3.36	3.64	3.96	3.76	3.40	2.92	2.48	1.9	2.3	1.7	27	30
18.0	2.79	3.15	3.67	3.97	4.32	4.10	3.68	3.18	2.70	1.8	2.3	1.7	34	42
19.0										1.6	2.0			
20.0								(Sears)...		1.5	1.9			
21.0										1.4	1.9			

Taken from Publ. Groningen, van Rhijn, 1929, which see for far more detailed values for both latitude and longitude. An excess of stars, especially S. of 0° latitude, between longitudes 240° and 60°, and a deficit elsewhere (Sears, Mt. Wilson Contributions, 301, 346, 347, also Publ. Astron. Soc. Pacific, 40, 303, 1928).

TABLE 789.—Numbers and Equivalent Light of the Stars

The total of starlight is a sensible but very small amount. This table by Chapman, shows that up to the 20th magnitude the total light emitted is equivalent to 687 1st-magnitude stars, equal to about the hundredth part of full moonlight. If all the remaining stars are included, following the formula, the equivalent addition would be only three more 1st-magnitude stars. The summation leaves off at a point where each additional magnitude is adding more stars than the last. But, according to the formula, between the 23d and 24th magnitudes there is a turning point, after which each new magnitude adds less than before. The actual counts have been carried so near this turning point that there is no reasonable doubt of its existence. Given its existence, the number of stars is probably finite, a conclusion open to very little doubt. Van Rhijn estimates the total number of stars at 30,000,000,000. Equivalent to 1440 stars of 1st visual magnitude in zenith, 1674 outside earth's atmosphere. Density of radiation = 0.8×10^{-13} erg/cm³. Millikan's cosmic radiation density = 4×10^{-15} erg/cm³.

Magnitude, m	Number	Equivalent 1st mag. stars	Totals to magnitude, m	Magnitude, m	Number	Equivalent 1st mag. stars	Totals to magnitude, m
−1.6....	Sirius	11	..	9.0–10.0.....	174,000	69	380
−0.9....	α Carinae	6	..	10.0–11.0.....	426,000	68	448
0.0....	α Centauri	2	..	11.0–12.0.....	961,000	60	508
0.0–1.0....	8	14	33	12.0–13.0.....	2,020,000	51	559
1.0–2.0....	27	17	50	13.0–14.0.....	3,960,000	40	599
2.0–3.0....	73	18	68	14.0–15.0.....	7,820,000	31	630
3.0–4.0....	189	19	87	15.0–16.0.....	14,040,000	22	652
4.0–5.0....	650	26	113	16.0–17.0.....	25,400,000	16	668
5.0–6.0....	2,200	35	148	17.0–18.0.....	38,400,000	10	678
6.0–7.0....	6,600	42	190	18.0–19.0.....	54,600,000	6	684
7.0–8.0....	22,550	56	246	19.0–20.0.....	76,000,000	3	687
8.0–9.0....	65,000	65	311	All stars fainter than 20.0...	..	3	690

Practically all the stars visible to the naked eye lie within 1000 parsecs of the sun, and most of them are more than 100 parsecs distant. In the vicinity of the sun, the majority of the stars lie within two or three hundred parsecs of the galactic plane; but along this plane the star-filled region extends far beyond 1000 parsecs in all directions, and may reach 30,000 parsecs in the great southern star clouds (Shapley).

TABLE 790.—The First-Magnitude Stars

No.	Star	m Mag.	Spectrum.	R.A. 1900	Dec. 1900	Annual proper motion, μ	P.A. of μ	π Parallax	Abs. mag.	Radial velocity km.
1	Achernar	0.6	B5	1^h 34.0^m	−57° 45′	0.094″	108°	+0.051″	−0.9	..
2	Aldebaran‡	1.1	K5	4 30.2	+16 18	.203	160	+ .062	−0.0	+55.1
3	Capella†‡	0.2	G	5 9.3	+45 54	.437	168	+ .075	−0.5	+30.2
4	Rigel*†	0.3	B8	5 9.7	− 8 19	.001	135	+ .007	−5.5	+22.6
5	Betelgeuse†§	0.6–1.2	Ma	5 49.8	+ 7 23	.029	74	+ .019	−2.7	+21.3
6	Canopus	−0.9	F	6 21.7	−52 38	.018	56	+ .007	−6.7	+20.8
7	Sirius*	−1.6	A	6 40.7	−16 35	1.316	204	+ .376	+1.2	− 7.4
8	Procyon*	0.5	F5	7 34.1	+ 5 29	1.242	214	+ .309	+3.0	− 3.5
9	Pollux§	1.2	K	7 39.2	+28 16	.625	264	+ .064	+0.2	+ 3.9
10	Regulus‡	1.3	B8	10 3.0	+12 27	.247	269	+ .033	−1.1	− 9.1
11	α Crucis*	1.1	B1	12 21.0	−62 33	.048	240	+ .047	−0.5	+ 7.0
12	β Crucis†	1.5	B1	12 41.9	−59 9	.056	240	+ .008	−4.0	+13.0
13	Spica†	1.2	B2	13 19.9	−10 38	.055	229	− .012	..	+ 1.6
14	β Centauri†	0.9	B1	13 56.8	−59 53	.041	219	+ .037	−1.3	− 7.0
15	Arcturus	0.2	K	14 11.1	+19 42	2.282	209	+ .075	−0.5	− 3.9
16	α Centauri*	0.3	G	14 32.8	−60 25	3.680	281	+ .759	+4.7	−21.6
17	Antares‡†	1.2	Ma	16 23.3	−26 13	.034	192	+ .029	−1.5	− 3.1
18	Vega§	0.1	A	18 33.6	+38 41	.346	36	+ .001	−0.1	−13.8
19	Altair§	0.9	A5	19 45.9	+ 8 36	.655	54	+ .214	+2.5	−33.0
20	Deneb§	1.3	A2	20 38.0	+44 55	.001	180	+ .002	−7.2	− 4.0
21	Fomalhaut	1.3	A3	22 52.1	−30 9	.365	117	+ .138	+2.0	+ 6.7

* Visual binary. † Spectroscopic binary. ‡ Pair with common proper motion. § Wide pair probably optical

Mass relative to sun of (7) is 3.1; of (8), 1.5; of (16), 2.0. For description of types, see Table 787 or Annals of Harvard College Observatory, 28, p. 146, or more concisely 56, p. 66, and 91, p. 5. The light ratio between successive stellar magnitudes is $\sqrt[5]{100}$ or the number whose logarithm is 0.4000, viz., 2.512. The absolute magnitude of a star is its magnitude reduced to a distance corresponding to 0.1″ parallax = $5+5\log\pi$.

TABLE 791.—Stars Known to be Within Five Parsecs of the Sun

The number of stars (doubles counted as singles) per cubic parsec in the neighborhood of the sun has been estimated as 0.0451 (Kapteyn, Van Rhijn, Astron. Journ., 52, 32, 1920). This gives as expectance of 24 within 5 parsecs and 12 nearer than 4. The numbers actually known are 28 and 19. It seems improbable that we should already know practically all within these limits. (Van Maanen, Mt. Wilson, 1930.) See note bottom page 620.

See Luyten, Ann. Harvard Obs., 85, 1923, for stars within 10 parsecs.

Star	Right Ascension 1900	Declination 1900	App. mag.	Parallax	Abs. mag.	Spectrum class	Proper motion
	h m	° ′		″			″
α Centauri A	14 32.8	−60 25	0.33	.763	4.74	G6	3.66
α " B	14 32.8	−60 25	1.70	.763	6.11	K4	3.66
α " C	14 32.8	−60 25	(10.5)	.763	14.9	(M)	(3.66)
(Barnard's star)	17 52.9	+ 4 28	9.67	.538	13.32	Mb	10.30
Wolf 359	10 51.6	+ 7 37	13.5	.407	16.5	M4e	4.84
Lalande 21185	10 57.9	+36 38	7.60	.380	10.5	Ma	4.77
α Canis Majoris A	6 40.7	−16 34	− 1.58	.358	1.19	A0	1.32
α " " B	6 40.7	−16 34	8.44	.358	11.21	(A)	1.32
Innes' star	11 12.0	−57 2	(12)	.345	14.69	..	2.69
BD −12°4523	16 24.8	− 2 24	9.5	.327	12.1	M5	1.24
α Canis Minoris A	7 34.1	+ 5 29	0.48	.318	2.99	F3	1.24
α " " B	7 34.1	+ 5 29	(12.5)	.318	15.0	..	1.24
τ Ceti	1 39.4	−16 28	3.65	.318	6.16	G7	1.92
Zc 5h 243	5 7.7	−44 59	8.3	.310	10.8	K2	8.70
61 Cygni A	21 2.4	+38 15	5.57	.305	7.99	K7	5.21
" " B	21 2.4	+38 15	6.28	.305	8.70	K8	5.21
ε Eridani	3 28.2	− 9 48	3.81	.301	6.21	K1	.97
Σ 2398 A	18 41.8	+59 29	9.33	.293	11.7	Mb	2.28
Σ " B	18 41.8	+59 29	10.01	.293	12.4	(M)	2.28
ε Indi	21 55.7	−57 12	4.74	.280	7.08	K5	4.67
Groombr. 34 A	0 12.5	+43 27	7.98	.277	10.19	Ma	2.85
" " B	0 12.5	+43 27	11.05	.277	13.26	(M)	2.85
Krüger 60 A	22 24.5	+57 12	9.64	.258	11.73	Mb	.94
" " B	22 24.5	+57 12	11.34	.258	13.40	(M)	.94
Lacaille 9352	22 59.4	−36 26	7.44	.256	9.48	Ma	7.02
Van Maanen's star	0 43.9	+ 4 55	12.34	.256	14.38	F0	3.01
Lacaille 8760	21 11.4	−39 15	6.65	.232	8.48	Ma	3.53
Gou 32416	23 59.5	−37 51	8.5	.220	10.2	K5	6.11
WB 10h 234	10 14.2	+20 22	9.2	.217	10.9	Mdp	.490
Lalande 25372	13 40.7	+15 26	9.6	.213	11.2	Mb	2.298
Oe Arg 17415–6	17 37.0	+68 26	9.2	.209	10.8	Mb	1.31
Wolf 562	15 14.2	− 7 21	10.7	.209	12.3	M5	1.33
Groombr. 1618	10 5.3	+49 58	6.82	.208	8.41	K6	1.451
BD +43°4305	22 42.5	+43 48	9.5	.208	11.1	Me5	.86
40 Eridani A	4 10.7	− 7 49	4.48	.200	6.0	G5	4.082
" " BC	4 10.7	− 7 49	9.7	.200	11.2	A	4.027
α Aquilae	19 45.9	+ 8 36	0.89	.198	2.37	A5	.65
Our sun			−26.72		+ 4.85	G0	

SPECTROSCOPIC DATA

(Mostly derived by permission from Russell, Dugan, and Stewart, Astronomy, Ginn & Co., 1917.)

TABLE 792.—Percentage of Stars of Various Spectrum Classes (Henry Draper Catalogue)

Visual magnitude	B (B0 to B5)	A (B8 to A3)	F (A5 to F2)	G (F5 to G0)	K (G5 to K2)	M (K5 to M8)
Brighter than 2.24	28	28	7	10	15	12
2.25 to 3.24	25	19	10	12	22	12
3.25 to 4.24	16	22	7	12	35	8
4.25 to 5.24	9	27	12	12	30	10
5.25 to 6.24	5	38	13	10	28	6
6.25 to 7.24	4	30	12	14	33	7
7.25 to 8.24	2	26	11	16	37	8
8.25 to 9.24	1	27	10	21	34	7
Below 9.25	1	33	8	25	29	4
All together	2	29	9	21	33	6

Among 6000 brighter than 6.25 m only 20 are recorded at Harvard as Class O, 8 of N. The brightest stars of Class O are γ Velorum (2.22 m) and ζ Puppis (2.27 m); of Class N, 19 Piscium (5.30 m); only about 70 of Class R and 20 of S known. Brightest R, $-10°5057$, (7.04 m); S, 2 Gruis (6.65 m).

TABLE 793.—Galactic Concentration of Various Spectrum Classes (Henry Draper Catalogue)

Above 7.0 mag.	B	A	F	G	K	M	All
40° to 90°	0.2	6.6	3.0	3.4	10.2	1.5	24.9
0°	10.8	21.1	5.1	5.1	15.1	3.9	61.1
7.0 to 8.25 mag.							
40° to 90°	0.1	6.6	9.5	16.4	32.8	6.1	71.5
0°	18.9	75.8	13.6	20.9	53.9	13.6	196.7

Star density per 100 sq. degrees. O stars entirely confined to Milky Way. N stars also strong galactic concentration.

TABLE 794.—Distribution of Binaries as to Spectrum Class

Brighter 8.75 mag.	No.	O—B8	B9—A3	A5—F2	F5—G2	G5—K2	K5—M
All stars	98675	5	24	11	19	35	8
Visual pairs	3939	4	32	14	28	21	1
Eclipsing pairs	132	18	58	12	8	3	1
Visual orbits	110	1	16	15	47	17	4

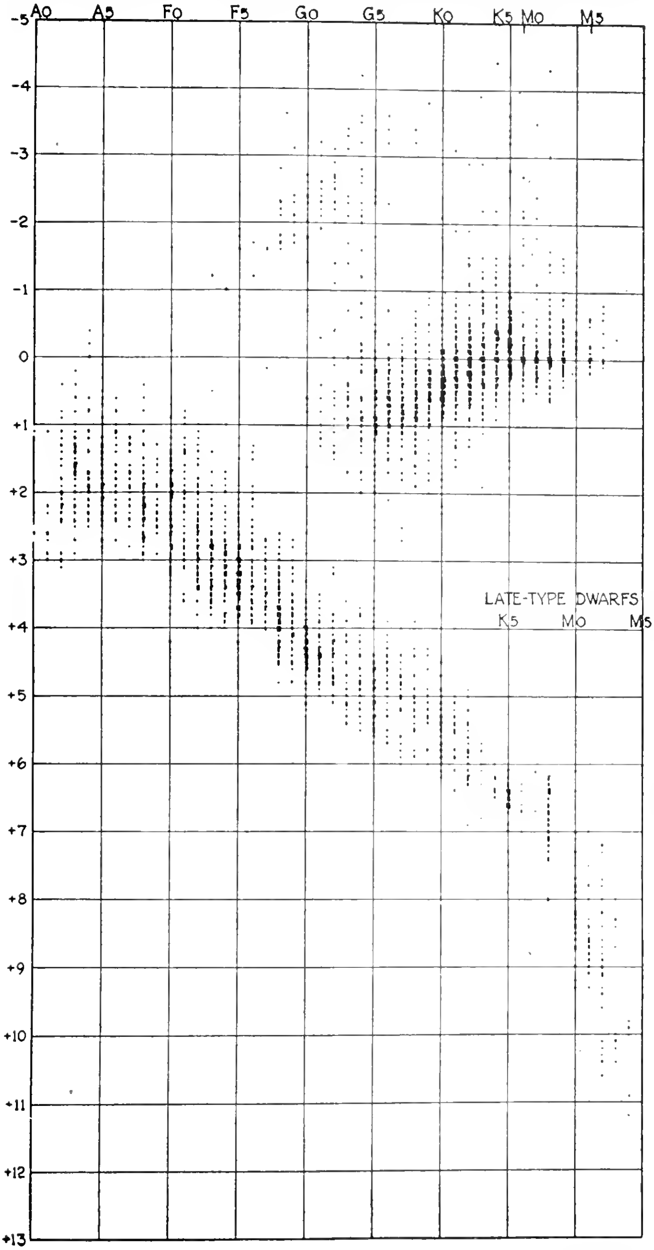
TABLE 795.—Masses of Spectroscopic Binaries, Sun = 1

Class	O8	B0 to B2	B3 to B5	B8 to A3	A5 to F3	F3 to G5
No. of stars	1	8	8	22	12	12
Inferior limit $M_1\sin^3 i$	75	12.2	4.9	2.3	1.4	1.2
" " $M_2\sin^3 i$	63	9.4	3.5	2.0	1.1	1.1
Ratio	.84	.77	.71	.87	.79	.89

NOTE.—16 Urs. Maj., spec. binary, F8 dwarf, RA $9^h 6^m$, dec. $+61° 51'$, annual p. m. 0.032″, $M+4$, π 0.06, rad. veloc. -15.0 km/sec. in about 10^6 yrs will pass within 2 parsecs of sun. Barnard's star and α Centauri are only two stars known closer than 2 parsecs. They will pass the sun distant 1.1 and 0.93 parsecs. Kapteyn's star was distant 1.6 parsecs 10,000 years ago; 279 Sagittarii, 1.4 parsecs, 35,000 years hence. (Pop. Astron. 32, 324, 1924.)

RUSSELL DIAGRAM

Absolute magnitudes (ordinates) of 3,915 stars of different spectrum types (abscissae) determined by the spectroscopic method by Dr. W. S. Adams and his associates. (Courtesy of Mt. Wilson Observatory, 1932.) The diagram shows the division of types G, and later, into giants (high luminosity stars) and dwarfs (low luminosity) with few or no intermediate stars. It resembles an inverted 7, and with the addition of much new material confirms fully that first drawn by Russell in 1913.



The stars may be divided into dwarfs, giants and supergiants. In each class the absolute magnitude progresses nearly linearly with spectral type except for the coolest stars; the direction of change is opposite for the dwarfs from that for the giants and supergiants. The luminosity of the dwarfs decreases regularly with advancing type (reduced surface temperature); it drops abruptly for the coolest. Among the giants and probably the supergiants the luminosity increases with decreasing temperature at least as far as the early subdivisions of type M.

The sequence of normal giants, conspicuous in types G, K, M, is almost missing for F5 and Go, the luminous stars of these latter types being supergiants. If this sequence is present in type A stars, they are intermingled with the dwarf sequence; the two sequences appear to cross in near type Fo. If so, the more luminous stars of types earlier than A should be those of the main dwarf series sequence. The tendency of both giants and dwarfs, especially giants, to group around definite values of absolute magnitude is remarkable. About 90 per cent of the Ko stars fall within limits of less than one magnitude. The hottest stars extend dwarf sequence up and to the left (Table 797). The white dwarfs belong to the lower left corner (Table 828), F to A, M 15 ±.

TABLE 797.—Spectrum Types and Absolute Magnitudes

(Strömberg, Mt. Wilson, Astrophys. Journ., 72, 111, 1930; 73, 40, 1931; 74, 110 and 342, 1931. See also Wilson, Astron. Journ., 41, 169, 1932.)

Statistical discussion of distribution of absolute magnitudes among the various spectrum groups. Figures marked** relate to supergiants,* normal giants,† dwarfs,*† normal giants and dwarfs, and refer to the groups of which the numbers thus marked are maxima. The subscripts are the percentages in the various groups. The first line of the table shows the number of stars used in the discussion for the column, but the figures in the columns are reduced so that the distribution is for 1000 stars in each group.

Number	124	246	152	351	416	558	622	601	1058	375	539
Abs. Mag.	Bo to B2	B3	B5	B8 to B9	Ao	A2 to A5	Fo to F9	Go to G9	Ko to K2	K3 to K9	M
−9.2	1	..	..	..	..	..	..	..	..	..	..
8.8	7	..	..	..	..	..	..	..	..	..	..
8.4	11	..	..	..	..	..	..	..	..	..	..
8.0	**12_{2}****	..	..	..	..	..	..	..	..	..	..
7.6	9	..	..	..	..	..	..	..	..	..	..
7.2	5	..	..	..	..	..	..	..	..	..	..
6.8	0	..	..	..	..	..	..	..	..	..	..
6.4	0	3	..	..	3	..	..	..	..	..	..
6.0	2	8_{2}**	..	..	7	..	..	..	..	..	..
5.6	**14_{18}****	4	..	..	8_{4}**	..	..	..	0	4	1
5.2	10	0	..	..	8	..	2	3	0	10	12
4.8	2	17	8	4	6	1	3	9	0	14	24
4.4	38	43	32	17	3	8	6	14	2	**15_{7}****	**28_{9}****
4.0	80	**53_{18}****	**50_{17}****	33	0	19	14	22	8	13	23
3.6	116	53	50	**38_{15}****	0	28	**18_{9}****	27	14	11	4
3.2	230	16	26	32	0	**32_{15}****	15	**27_{19}****	20	8	0
2.8	**262_{80}****	0	2	22	0	29	13	25	25	12	0
2.4	107	16	4	6	0	22	16	31	**26_{14}****	21	2
2.0	39	120	103	0	0	9	3	27	23	33	26
1.6	13	228	**232_{83}***	0	1	1	0	2	6	46	74
1.2	1	**229_{80}***	219	22	5	0	0	0	10	66	116
0.8	4	125	131	210	13	0	0	0	23	111	148
−0.4	**20***	64	86	**248_{85}***	34	1	1	1	99	171	**157_{91}***
0.0	13	19	37	206	167	34	23	88	235	**185_{90}***	149
+0.4	4	2	13	100	**254_{96}***	132	56	**238_{49}***	**269_{78}***	112	135
0.8	..	..	6	43	249	189	91	133	111	58	62
1.2	..	..	1	17	162	**192_{85}*†**	**120_{45}***	30	24	36	22
1.6	..	..	..	2	53	160	109	10	17	25	5
2.0	..	..	..	..	22	98	46	32	14	15	..
2.4	..	..	..	.	5	28	38	48	15	7	..
2.8	..	..	..	..	..	8	100	**$53_{23,9}$*†**	**18_{6}†***	3	..
3.2	..	..	..	..	..	5	**139_{46}†**	50	14	0	..
3.6	..	..	..	..	..	3	111	38	4	0	..
4.0	..	..	..	..	..	1	52	36	0	0	..
4.4	..	..	..	..	..	..	19	32	0	0	..
4.8	..	..	..	..	..	..	5	18	0	0	..
5.2	..	..	..	..	..	..	0	5	1	0	..
5.4	..	..	..	..	..	..	0	1	3	2	..
5.8	..	..	..	..	..	..	..	..	**4_{1}†**	3	..
6.2	..	..	..	..	..	..	..	..	4	6	..
6.6	..	..	..	..	..	..	..	..	1	**7_{2}†**	..
7.0	..	..	..	..	..	..	..	..	0	5	...
7.4	..	..	..	..	..	..	..	..	0	1	..

Summary (mean abs. magnitude)

Spectrum	No. stars	Super-giants	Bright giants	Normal giants	Faint giants	Dwarfs
Mo to M9	247	−4.5(9)	....	−0.2(91)	....	....
K3 " K9	378	−4.5(7)	....	−0.1(91)	....	+6.7(2)
Ko " K2	1058	....	−2.5(14)	+0.3(78)	+2.7(7)	+6.1(1)
Go " G9	601	−3.0(19)		+0.4(49)	+2.8(23)	+4.2(9)
Fo " F9	622	−3.0(9)		+1.2(25)	+3.2(46)	
A2 " A5	478	−3.2(15)		....	+1.2(85)	

The small percentage of dwarf stars is due to the fact that their apparent magnitudes in most cases are fainter than the set limit of 6.0.

TABLE 798.—Brightness of the Stars

Stellar magnitudes give the apparent brightness of the stars on a logarithmic scale,—a numerical increase of one magnitude corresponding to a *decrease* of the common logarithm of the light by 0.400, and a change of five magnitudes to a factor of 100. The brightest objects have negative stellar magnitudes. The visual magnitude of the Sun is -26.7; of the mean full Moon, -12.5; of Venus at her brightest, -4.3; of Jupiter, at opposition, -2.3; of Sirius, -1.6; of Vega, $+0.2$; of Polaris, $+2.1$. (The stellar magnitude of a standard candle 1 m distant is -14.18.) The faintest stars visible with the naked eye on a clear dark night are of about the sixth magnitude (though a single luminous point as faint as the eighth magnitude can be seen on a perfectly black background). The faintest stars visible with a telescope of aperture A in. are approximately of magnitude $9 + 5 \log_{10} A$. The faintest photographed with the 100-inch reflector at Mt. Wilson are of about the 22nd magnitude. A standard candle, of the same color as the stars, would appear of magnitude $+0.8$ at a distance of one kilometer.

The actual luminosity (absolute magnitude) is the stellar magnitude which the star would have if placed at a distance of ten parsecs. The faintest star at present known (Innes), a distant companion to α Centauri, has the (visual) absolute magnitude $+15.4$, and a luminosity 0.00006 that of the sun. The brightest so far definitely measured, β Orionis, has (Kapteyn) the abs. mag. -5.5 and a luminosity 13,000 times the sun's. Canopus, and some other stars, may be still brighter. Note 1931: S. Doradus abs. mag. probably > -8.

The absolute magnitudes of 6 planetary nebulae average 9.1; average diameter, 4000 astronomical units (Solar system to Neptune = 60 astr. units), van Maanen, Proc. Nat. Acad. Sci. 4, p. 394, 1918.

TABLE 799.—Giant and Dwarf Stars

The stars of Class B are all bright, and nearly all above the absolute magnitude zero. Stars of comparable brightness occur in all the other spectral classes, but the inferior limit of brightness diminishes steadily for the "later" or redder types. The distribution of absolute magnitudes conforms to the superposition of two series, in each of which the individual stars of each spectral class range through one or two magnitudes on each side of the mean absolute magnitude. Absolute magnitude supergiants -2 to -8; giants roughly 0 to $+1$; dwarfs A, 1 to 2; F, 2 to 4; G, 4 to 6; K, 6 to 9; M, 9 to 11. The two series overlap in Classes A and F, are fairly well separated in Class K, and sharply so in Class M. Two very faint stars of Classes A and F fall into neither series.

The majority of the stars visible to the naked eye are giants since these, being brighter, can be seen at much greater distances. The greatest percentage of dwarf stars among those visible to the eye is found in Classes F and G. The dwarf stars of Classes K and M are actually much more numerous per unit of volume, but are so faint that few of the former, and none of the latter, are visible to the naked eye.

TABLE 800.—Masses and Densities

Stars differ less in mass than in any other characteristic. The most massive star known is the brighter component of the spectroscopic binary B.D. 6° 1309, 86 times the sun's mass, 113 times its luminosity, and spectrum Oe. The smallest known mass is that of the faint component of the visual binary Krueger 60, whose mass is 0.15, and luminosity 0.0004 of the sun's, and spectrum M. Note: Plaskett notes giant double star 184 sun's mass.

The giant stars are in general more massive than the dwarfs. According to Russell (Publ. Astron. Soc. America, 3, 327, 1917) the mean values of Binary systems are:

Spectrum	B2	Ao	F5 giant	K5 giant	F2 dwarf	G2 dwarf	K8 dwarf
Ratio of mass to Sun	12	6.5	8	10	3.0	1.2	0.9

The densities can be determined only for eclipsing variables. Stars of Classes B and A have densities averaging about one tenth that of the sun and a relatively small range; Classes F to K show a wide range in density, from 1.8 times that of the sun (W Urs. Maj.) to 0.000002 (W Crucis).

The surface brightness probably diminishes by at least one magnitude for each step along the Harvard scale from B to M. It follows that the dwarf stars are, in general, closely comparable with the sun in diameter, while the stars of Classes B and A, though larger, rarely exceed ten times the sun's diameter. The redder giant stars must be much larger, and a few, such as Antares, may have diameters exceeding that of the earth's orbit. The densities of these stars must be exceedingly low.

Arranged in order of increasing density, the stars form a single sequence starting with the giant stars of Class M, proceeding up that series to Class B, and then down the dwarf series to Class M.

Star	Type	Mag.	Diam.	Parallax	Mass	Density	Brightness	Diameter (km)
Antares	Map	1.2	″.038	″.013	30.	.0000010	1600.	440,000,000
Betelgeuse	Ma	0.9	.044	.018	30.	.0000012	1450.	378,000,000
α Hercules	Mb	3.5	.015	.007	30.	.0000020	710.	330,000,000
Aldebaran	K5	1.5	.027	.075	10.	.00017	36.	53,000,000
Arcturus	Ko	0.2	.023	.095	10.	.0007	78.	37,000,000
Rigel	B8	0.3	.0019	.007	30.	.0012	13500.	40,000,000
Capella	Go	0.2	.0082	.071	4.6	.006	78.	13,000,000
Vega	Ao	0.1	.0026	.004	5.	.21	86.	4,200,000
Sirius	Ao	− 1.6	.0057	.376	2.5	.62	26.	2,300,000
Procyon	F5	0.5	.0048	.328	2.	.60	5.	2,300,000
Our Sun	G	−26.5	960.	—	1.	1.	1.	1,391,000
Krueger 60	Mb	9.3	.0011	.260	.42	4.0	0.002	580,000
Prox. Cent.	N	11.0	.0017	.76	.055	4.0	.00006	333,000
Barnard's	Mb	9.7	.0009	.53	.023	4.0	.0004	249,000

Computed by Plaskett, Publ. Ast. Soc. Pac. 1922; Interferometer measurements, Antares, 0.024″, 30,600,000 km; Betelgeuse, 0.047″, 386,000,000 km. (1921).

TABLE 801.—Parallax and Mean Apparent Magnitude

(Reprinted by permission from Russell, Dugan, and Stewart, Astronomy, Ginn & Co., 1927.)

Magnitude	Mean parallax	m	p	m	p
1	0″.083	6	0″.0120	11	0″.0018
2	.056	7	.0082	12	.0013
3	.038	8	.0056	13	.0009
4	.026	9	.0039		
5	.018	10	.0027		

TABLE 802.—Spectrum Type and Mean Absolute Magnitude

(Trumpler, Bull. Lick Obs., No. 420, 1930.)

	Mean absolute magnitude Dwarf branch			Mean absolute magnitude Dwarf branch		Giants	
Type	Vis.	Phtgr.	Type	Vis.	Phtgr.	Vis.	Phtgr.
O	−4.0	−4.3	A3	+2.0	+2.1		
B0	−3.1	−3.4	A5	+2.3	+2.5		
B1	−2.5	−2.8	F0	+2.9	+3.2	+0.5	+0.9
B2	−1.8	−2.1	F2	+3.2	+3.5		
B3	−1.2	−1.4	F5	+3.6	+4.0	+ .5	+1.0
B5	− .8	−1.0	F8	+4.2	+4.7		
B8	− .2	− .3	G0	+4.5	+5.1	+ .5	+1.2
B9	+ .3	+ .3	G5	+5.0	+5.7	+ .5	+1.4
A0	+ .9	+ .9	K0	+6.2	+7.0	+ .5	+1.6
A2	+1.7	+1.7					

Based on Adams, Joy, Mt. Wilson Contr. 199, 244, 262; Lundmark, Publ. Astron. Soc. Pacific, 34, 1922; Malmquist, Meddel. Lund. II, 32, 1924; Hess, Seeliger Festschrift, p. 265, 1924.

TABLE 803.—Reduction of Visual to Bolometric Magnitude

Eddington (M. N. 177, 605) gives the corrections from visual to bolometric magnitudes for the cooler stars. For the hotter stars the data are not so certain. The values are to be added algebraically to the absolute visual magnitudes.

O5	−3.60	A0	−0.31	F5	0.00	gM5	−1.5	dK4	−0.50
O6	−3.30	A1	− .27	F6	.00	dG0	− .01	dK5	− .60
O7	−2.90	A2	− .23	F7	− .02	dG1	− .02	dK6	− .71
O8	−2.50	A3	− .19	F8	− .03	dG2	− .02	dK7	− .82
O9	−2.10	A4	− .15	F9	− .05	dG3	− .02	dK8	− .93
B0	−1.80	A5	− .12	gG0	− .10	dG4	− .03	dK9	−1.05
B1	−1.65	A6	− .09	gG2	− .14	dG5	− .03	dM0	−1.17
B2	−1.50	A7	− .06	gG5	− .17	dG6	− .03	dM2	−1.30
B3	−1.35	A8	− .04	gG6	− .18	dG7	− .04	dM3	−1.43
B4	−1.20	A9	− .02	gG7	− .21	dG8	− .06	dM4	−1.56
B5	−1.00	F0	− .02	gG8	− .25	dG9	− .09	dM5	−1.71
B6	− .85	F1	− .01	gK0	− .39	dK0	− .14	dM6	−1.85
B7	− .65	F2	− .01	gK3	− .65	dK1	− .22	dM7	−2.05
B8	− .53	F3	.00	gK4	− .74	dK2	− .31	dM8	−2.30
B9	− .39	F4	.00	gK5	− .83	dK3	− .40	dM9	−2.59

TABLE 804.—Summary, Elements of Solar Motion (Campbell, 1928)

(Publ. Lick Obs., vol. 16, 1928.)

Charlier	α_0, 269.3°	δ_0, +30.8°	v_0, 19.0 km/sec.	1986 r. v.; 4182 p. m.; 646π
Strömberg	272.1	+29.5	20.6	Space veloc. 1026, A6-M.
Wilson	270.8	+27.1	19.0	2748, 2305, r. v. and p. m.
Campbell, Moore	270.58	+29.24	19.65	2149 r. v. B-M stars
Mean	270.70	+29.16	19.55	

Dwarf stars decidedly higher space velocity than giants (Strömberg).

Class B (O05-B5)	v_0 = 22.7 km/sec.	K = +4.9	K (G5-K4)	v_0 = 18.0 km/sec.	K = +0.3
A (B8-A3)	18.6	+1.7	M (K5-Mb)	22.1	+ .7
F (A5-F4)	19.7	+ .3	B-M	19.7	+1.26
G (F5-G4)	18.6	− .2			

Dwarfs appear only in classes F, G; remove 3 from G, v_0 = 16.6 km/sec.

TABLE 805.—Elements of Solar Motion (Charlier, 1926)

(Charlier, The motion and the distribution of the stars, Mem. Univ., California, vol. 7, 1926.)

Radial velocities lead to conclusion stars are receding.
Galactic coordinates of apex.

Type	No. stars	Galac. long. °	Galac. lat. °	Mag.	No. stars	Galac. long. °	Galac. lat. °
B stars.......	694	26.7	+17.3	5.0–5.9........	454	20	+22
A "	1281	18.6	+22.8	6.0–6.9........	1003	29	+16
F "	508	17.8	+20.4	7.0–7.9........	1239	55	+17
G "	379	29.7	+28.6	8.0–8.9........	811	37	+24
K "	1135	37.7	+17.8	8.6............	276	55	+23
M "	190	31.5	+20.6	11.1...........	203	69	+24

1986 (rad. v.), 646 (parallax stars); sun's velocity = 19.0 km/sec.
(4 astr.units/yr.). 1986 (rad. v.), 646 (par. stars), 4182 (p. m. stars) give as apex. Galac. long., 24°.3, latitude, +22°.44; α = 269.3, δ = +30°.85

TABLE 806.—Stars of Large Proper Motion

	Mag.	p. m. ″	spect.		Mag.	p. m. ″	spect.
Barnard's..............	9.7	10.2	M5	O_2 Eridani (triple).......	4.5	4.1	G5
Kapteyn's..............	9.2	8.8	Mo	Wolf 489................	13	3.9	...
Gr. 1830...............	6.5	7.0	G5	Prox. Centauri..........	10.5	3.8	M?
Lacaille 9352...........	7.4	6.9	Mo	μ Cassiopeiae...........	5.3	3.8	G5
Cordoba 32416..........	8.3	6.1	M3	α Centauri (double).....	.3	3.7	Go
61 Cygni (double).......	6.3	5.2	K8	Washington 5584 (double)	8.9	3.7	Go
Wolf 359................	13	4.8	...	Cordoba 29191..........	6.6	3.5	Mo
Lalande 21185..........	7.6	4.8	M2	ϵ Eridani................	4.3	3.2	G5

In case of multiple stars the magnitudes and spectra of the brightest star are indicated.

See Lick Obs. Bull. 344; Harvard Circular 283; also Luyten, Astronom. Journ. 42, 69, 1932. List of stars, p. m. > 0″.5 annually. The following stars, Van Maanen's, 3″.01, Ross 619, R. A. 8^h06^m, Dec. + 92, annual p. m. 5″.40, may be added to the above list.

TABLE 807.—Spectrum Class and Proper Motions

(Reprinted by permission from Russell, Dugan, and Stewart, Astronomy, Ginn & Co., 1927.)

Limits of p. m.	O	B	A	F	G	K	M	N
0″.00 to 0″.02	13	238	392	97	107	218	48	3
0 .02 to 0 .04	6	164	533	115	91	327	54	4
0 .04 to 0 .10	1	88	476	231	168	393	99	2
0 .10 to 0 .20	..	..	160	245	70	242	27	1
0 .20 to 0 .45	..	1	31	168	56	88	8	..
0 .45 to 0 .80	..	..	1	46	20	23	1	..
0 .80 to 2 .00	..	..	1	12	19	13	..	..
Over 2″.00	..	..	..	1	6	6	..	..
Mean p. m.	0″.22	0″.03	0″.06	0″.17	0″.18	0″.12	0″.07	0″.04
Percentage of stars with $\mu > 0''.20$	0	0.2	5	25	18	10	4	0

TABLE 808.—Equipartition of Energy in Stellar Motions

(Jeans, Nature, 122, 689, 1928.)

Type.	Mean mass.	Mean velocity.	Mean energy.	Corresponding temperature.
B3	19.8×10^{33}	14.8×10^{5} cm/sec.	1.95×10^{46}	1.0×10^{62} °K.
B8.5	12.9 "	15.8 "	1.62 "	0.8 "
A0	12.1 "	24.5 "	3.63 "	1.8 "
A2	10.0 "	27.2 "	3.72 "	1.8 "
A5	8.0 "	29.9 "	3.55 "	1.7 "
F0	5.0 "	35.9 "	3.24 "	1.6 "
F5	3.1 "	47.9 "	3.55 "	1.7 "
G0	2.0 "	64.6 "	4.07 "	2.0 "
G5	1.5 "	77.6 "	4.57 "	2.2 "
K0	1.4 "	79.4 "	4.27 "	2.1 "
K5	1.2 "	74.1 "	3.39 "	1.7 "
M0	1.2 "	77.6 "	3.55 "	1.7 "

"This equality of energy can be attributable only to the gravitational interaction of the stars. For if it were produced by any physical agency, such as pressure of radiation, bombardment by molecules, atoms, or high-speed electrons, this agency, as the last column shows, would have to be in thermodynamical equilibrium with matter at a temperature of the order of 2×10^{62} °K. Since no such temperatures are known the observed equality must be due to gravitational interactions over millions of years. Such evidence suggests a general age of the stars of 5 to 10 million-million years."

TABLE 809.—Stars of Large Space Velocity, Greater Than 300 km/sec.

Right ascension 1900	Declination 1900	App. magnitude	Parallax π	Apex of motion: Right ascension	Apex of motion: declination	Velocity km/sec.	Right ascension 1900	Declination 1900	App. magnitude	Parallax π	Apex of motion: Right ascension	Apex of motion: declination	Velocity km/sec.
°	°		″	°	°		°	°		″	°	°	
8.5	+ 2.6	7.4	0.007	100	+23	543	223.6	−21.6	8.5	0.009	145	−45	429
15.8	+61.0	7.8	.015	149	−46	369	226.2	−16.0	9.9	.034	189	−69	590
32.4	− 1.7	9.2	.013	121	− 3	362	226.2	−15.9	9.4	.034	187	−69	583
62.2	+22.1	8.9	.008	97	− 4	448	227.1	+19.7	7.3	.006	124	+24	509
72.8	+34.1	8.0	.006	150	−11	465	234.4	−10.6	7.3	.012	123	− 8	479
116.8	+30.9	8.2	.040	257	−64	333	245.4	+19.1	var.	.002	205	−69	409
127.3	−31.2	6.4	.008	57	+27	786	246.9	+48.2	7.0	.003	220	−42	482
128.6	+ 6.1	7.8	.002	213	−59	799	262.5	+ 6.1	8.5	.008	143	+37	395
135.4	+23.4	6.3, 7.1	.002	48	+ 3	371	263.5	+18.6	9.1	.002	167	−51	695
							264.1	+37.3	8.6	.013	302	−35	364
138.8	+34.8	3.3	.002	49	+ 6	501	304.4	−21.7	8.2	.012	92	−41	480
145.9	+14.2	8.1	.003	187	−50	787	308.6	+42.5	7.1	.003	90	+44	306
153.6	+20.4	3.2	.004	239	−27	420	314.8	+ 2.6	8.1	.003	228	−51	767
176.8	+38.4	6.5	.101	243	−49	346	341.6	+13.4	8.0	.005	78	+28	440
180.0	− 1.0	8.4	.004	92	+ 7	617	355.0	+29.0	8.9	.009	80	+ 6	466
182.0	+10.6	8.0	.005	256	−58	408							
192.0	−18.0	8.3	.011	273	−67	418							
222.0	+19.2	8.0	.002	55	+66	444							

This and the following table are taken from Katalog von 1937 absoluten Sterngeschwindigkeiten, Klumak, Hecht, Astron. Nachr. no. 5696-7, 238, 116, 1930. See also Wilson, Raymond, Astron. Journ. 40, 121, 1930, 4233 stars.

TABLE 810.—Stars of Small Space Velocity, 5 km/sec. or less

Same reference and designations as for preceding table.

Right ascension 1900	Declination 1900	App. magnitude	Parallax π	Apex of motion: Right ascension	Apex of motion: declination	Velocity km/sec.	Right ascension 1900	Declination 1900	App. magnitude	Parallax π	Apex of motion: Right ascension	Apex of motion: declination	Velocity km/sec.
°	°		″	°	°		°	°		″	°	°	
8.7	+56.0	2.5	0.016	345	+34	5	185.2	+39.6	5.2	0.021	180	+ 9	4
16.0	+35.1	2.4	.045	95	−18	3	207.1	+18.4	5.7	.010	126	+ 7	4
18.1	−69.4	5.0	.160	315	− 6	5	224.6	−24.9	3.4	.025	193	+27	5
41.0	+26.9	3.7	.031	299	−57	5	241.4	+45.2	4.3	.014	41	+68	5
66.6	+42.8	6.8	.018	306	−61	4	255.8	+54.6	5.8	.044	157	+15	4
69.1	+22.8	4.3	.008	12	+45	4	268.9	+16.8	4.7	.011	125	−11	5
73.6	+60.3	4.2	.004	284	+ 9	5	274.1	+36.0	4.3	.042	146	− 1	5
92.7	+46.4	6.5	.035	243	−26	5	277.9	+52.3	5.4	.007	197	−31	5
99.5	+25.2	3.2	.007	230	+26	4	297.3	− 8.5	6.5	.010	16	+50	3
110.2	−31.6	5.4	.035	145	−14	5	297.4	+ 8.2	4.9	.038	0	−27	5
112.2	+56.0	6.0	.013	238	− 6	4	299.3	+27.5	4.7	.030	121	+ 9	5
131.1	+33.7	6.2	.038	274	+41	5	305.0	+31.9	4.6	.016	353	+31	4
156.4	+81.0	6.6	.005	271	−44	4	325.4	−16.6	3.0	.114	245	− 2	3
183.6	+28.7	6.3	.056	355	−76	5	349.0	+37.6	5.8	.035	330	−56	5

TABLE 811.—Motions of the Stars

The individual stars are moving in all directions, but, for the average of considerable groups, there is evidence of a drift away from the point in the heavens towards which the sun is moving (solar apex). The best determinations of the solar motion, relative to the stars as a whole, are given in Table 804. In round numbers this motion of the sun may be taken as 20 km/sec. towards the point R. A. 18 h. 0. m., Dec. + 30.0°.

After allowance is made for the solar motion, the motions of the stars in space, relative to the general mean, present marked peculiarities. If from an arbitrary origin a series of vectors are drawn, representing the velocities of the various stars, the ends of these vectors do not form a spherical cluster (as would occur if the motions of the stars were at random), but a decidedly elongated cluster, whose form can be approximately represented either by the superposition of two intermingling spherical clusters with different centers (Kapteyn's two-stream hypothesis) or by a single ellipsoidal cluster (Schwarzschild), the actual form, however, being more complicated than is indicated by either of these hypotheses. The direction of the longest axis of the cluster is known as that of preferential motion. The two opposite points in the heavens at the extremities of this axis are called the vertices. The components of velocity of the stars parallel to this axis average considerably larger than those parallel to any axis perpendicular to it.

The preferential motion varies greatly with spectral type, being practically absent in Class B, very strong in Class A, and somewhat less conspicuous in Classes F to M, on account of the greater mean velocities of these stars in all directions. The positions of the vertices are nearly the same for all.

Numerous investigators, from the more distant naked-eye stars, find substantially the same position for the vertex, the mean being R. A. 6 h. 6 m., Dec. + 9°. The nearer stars, of large proper motion, give a mean of 6 h. 12 m., + 25°. (See Strömberg's discussion, cited above.)

In addition to these general phenomena, there are numerous clusters of stars whose members possess almost exactly equal and parallel motions,—for example, the Pleiades, the Hyades, and certain large groups in Ursa Major, Scorpius, and Orion. The vertices, and the directions toward which these clusters are moving, are all in the plane of the galaxy.

The greatest known p. m. star is Barnard's 9th m. in Ophiuchus, 10.3″ per year, position angle 356°, parallax 0.52″, radial velocity about −117 km/sec.

The average radial velocity of the globular clusters is 100 km/sec. The globular clusters as a class are approaching the sun. The spiral nebulae are receding.

A general card catalogue of radial velocities is kept at the Lick Observatory. See Campbell, Radial velocities of 2600 stars, Lick Obs. Publ., vol. 16, 1928; of 741 stars, Adams, Joy, Strömberg, Sanford—Astroph. Journ. 70, 1929.

TABLE 812.—Known Stars of Radial Velocities Greater Than 100 km/sec.

Star	Mag.	Spectrum class	R. A. h. m.	Dec. ° ′	Proper motion	Velocity km/sec.
(1) RZ Lyrae	...	...	...	...	...	+385
(2) Washington 5583	9.1	G5	...	...	3.68	+307
(3) Washington 5584	8.9	G0	...	...	3.68	+295
(4) S Carinae	var.	Md	10 06	−61 4	...	+289
(5) Kapteyn's star	9.2	M0	...	...	8.76	+242
(6) Van Maanen No. 2	12.3	dF3	0 45	+ 5 2	3.01	+238
(7) Cord. 5.243	...	G-K	5 8	−45 59	...	+225
(8) R Pictoris	var.	Md	4 44	−49 26	...	+207
(9) A G Wash. 3498	9.4	A7	8 37	−16 4	.56	+200
(10) 41312 Boss 1511	5.2	G5	5 59	−26 17	...	+184
(11) ω Pavonis	5.1	K0	18 50	−60 20	...	+181
(12) Luyten 680	10.8	dG0	21 52	+32 17	.73	−178
(13) BD +34° 2476	9.3	A3sp	13 56	+34 16	.54	−164
(14) V Urs. Min	7.5-8.7	gM5	13 37	+74 41	...	−158
(15) BD +35° 3659	9.5	F0s	19 28	+36 1	.56	−172
(16) BD +6° 2932	9.5	dG1	14 40	+ 6 9	.93	−139
(17) AGC 27600	5.3	K5	20 5	−36 21	...	−130
(18) Barnard star	9.7	M5	...	...	10.25	−117
(19) μ Columbae	5.2	B2	5 42	−32 21	...	+110
(20) BD −3° 3746	9.2	dM0	15 10	− 3 32	.69	−106
(21) β GC 10404 br	8.5	gK4	20 36	+21 27	...	−106
(22) Cin. 2750	8	dF9	21 9	+23 51	.46	−103
(23) 172 G Puppis	5.4	F8	7 42	−33 59	...	+102
(24) γ 31 Aquilae	5.2	G5	19 20	+11 44	...	−101
(25) Boss 4188	5.4	Ma	16 22	− 7 22	...	+101
(26) δ Leporis	3.9	K0	5 47	−20 53	...	+100

(Tables abridged by permission from Russell, Dugan, and Stewart, Astronomy, Ginn & Co., 1927.)

TABLE 813.—Visual Binary Stars

Burnham's General Catalogue, 1906, 3,665 pairs. Card catalogue kept by Aitken at Lick Observatory. Of stars brighter than 6.5 mag., one in 9 visual double. See also Aitken, The binary stars, McMurtrie, 1918, and New General Catalogue, Carnegie Institution, 1932; Innis, Southern double star catalogue, 1927.

e is eccentricity, *a* major axis in seconds of arc, *A* in astronomical units of orbit.

Star	Magnitude	Spectra	Period	e	a	A	$m_1 + m_2$	m_1, m_2	Abs. mag.
α Aur	0.8, 1.1	G0, F5	0^y.285	0.01	0″.054	0.85	7.5	4.2, 3.3	−0.2, 0.1
δ Equ	5.2, 5.7	F5	5.70	.39	0.27	4.5	2.8	....	4.1, 4.6
α CMi	0.5, 13	F5	39.0	.32	4.05	13.0	1.5	1.1, .4	3.0, 15.5
α CMa	−1.6, 8.4	A0, F0	50.0	.60	7.57	20.4	3.4	2.44, .96	1.3, 11.3
ξ UMa	4.4, 4.9	F9, G2	59.8	.41	2.51	17	1.4	0.7, .7	5.2, 5.7
α Cen	0.3, 1.7	G0, K5	78.8	.51	17.65	23.3	2.04	1.10, .94	4.7, 6.1
ξ Boo	4.8, 6.7	G6, K4	152.8	.51	4.83	29	1.0	.53, .47	5.9, 7.8
o_2 Eri	9.7, 11.4	A0, M6	248	.40	6.89	34	0.64	.44, .20	11.4, 12.9
α Gem	2.0, 2.8	A0, A0	306	.56	6.06	80	5.5	....	1.4, 2.2
η Cas	3.7, 7.4	F8, K0	346	.33	10.1	55	1.4	.8, .6	5.0, 8.7

TABLE 814.—Spectroscopic Binary Stars

Stars so close not yet visually double. Discovered and studied through shift of spectrum lines (Doppler effect). *i* is inclination of orbit to "plane of sky," *m*, masses of components. The percentage with periods <10 d: 71 for O and B stars; 64, A; 52, F-G; 16, K-M; periods >100 d, percentages are 12, 6, 18, 61. See Lick Obs. Bull. No. 355.

Star	App. mag.	Class	Period days	Eccentricity	Orbital velocity	Asin i 10^6 km	$m_1 \sin^3 i$ $m_2 \sin^3 i$	$\frac{m_2^3 \sin^3 i}{(m_1+m_2)^2}$	Abs. mag.
μ Sco	3.1	B3	1.45	0.05	480	9.5	16.5	...	−2.2, −1.8
β Per	2.1	B8	2.87	.004	44	1.73	...	0.025	−0.7
"	..	..	688	.13	10	93	...	.070	...
α Gem B	2.8	A0	2.93	.01	32	1.28	...	.0097	...
" A	2.0	A0	9.22	.50	13.6	1.49	...	.0015	...
α Vir	1.2	B2	4.01	.10	126, 208	6.9, 4.4	9.6, 5.8	...	−2.6, −2.2
+ 6°1309	6.4	O8	14.41	.04	206, 247	41, 49	76, 63	13.2	...
ζ U MaA	2.4	A2	20.54	.54	69	16.4	1.66	.41	1.4
α Aur	0.2	G0	104	.01	26, 32	37, 46	1.2, 0.9	.18	...
ξ U MaA	4.4	G0	665	.41	7.0	58.3	...	.018	...
β Cap	3.2	G0	1375	.44	22.2	377	...	1.13	...

TABLE 815.—Spectroscopic Eclipsing Binaries

Some 200 known. Last column, distance between center of two stars = radius of relative orbit. See Shapley Contr. 3, Princeton Univ. Obs.

Name	Max. mag.	Sp. class	Period days	e	i	Radii sun = 1	Density sun = 1	Masses sun = 1	10^6 km
SW Lac	8.6	G2p	0.32	0.78	73°	0.42, 0.46*	1.6, 1.2	....	....
WU Ma	7.9	G0	.33	.85	76	.78, .78	2.1, 1.5	0.69, 0.49	1.53
S Ant	6.3	F0	.65	.75	62	1.7, 1.3	.31, .38	.75, .42	2.30
α Gem C	9.0	M	.81	...	86	.58, .58	2.6, 2.6	.52, .52	2.58
ν Pup	4.1	B1p	1.45	.88	74	8.4, 7.7	.04, .06	19 19	8.83
ω Her	4.6	B3	2.05	.93	74	4.6, 5.4	.09, .02	7.7, 2.9	10.3
U Cep	6.9	A0	2.49	.96	86	.20, .32*	.14, .03	....	....
β Pes	2.3	B8	2.87	.99	82	.21, .24*	.13, .03	....	1.76†
TX Cas	9.3	B3	2.93	.93	88	.57, .30*	.006, .02	....	....
β Aur	2.1	A0p	3.96	.99	77	2.8, 2.8	.11, .11	2.4, 2.4	12.3
RS Vul	6.9	B8	4.48	.98	79	4.3, 5.6	.06, .01	4.6, 1.4	14.5
S Cnc	8.2	A0	9.48	1.0	85	.10, .18*	.10, .01	....	....
W Cru	8.7	G0p	198	.91	76	.61, .34*	(1.3 × 10^{-6}, 3.1 × 10^{-6})		....
RZ Oph	9.7	cG0	262	...	87	.53, .47*	.05, .15	.001, .00003	....

* Radii in terms of the relative orbit as unit. † Radius of relative orbit.

Table 816

PERIODS OF KNOWN BINARY STARS WITHIN 10 PARSECS OF THE SUN

There is no reliable evidence (1930) for favored orientation of planes of double-star orbits. Kepler 3rd law gives (p, period in yrs.)^2 = (a, major axis, astr. units)^3/(M, in solar masses). There is an apparent statistical relation between eccentricity and period, viz.:

Eccentricity	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Period (logs)	.62	.66	.71	.76	.80	.83	.85

Using the mass-luminosity law (see p. 631) Luyten obtains: Log period in yrs. = 1.460 log d − 0.48 log (M, in solar air-masses) + 0.168 ± 0.35 where d is observed distance between stars at right angle to line of sight in astronomical units.

From the data of the following groups the median-mean log of the periods (median-geometrical mean of actual periods) is probably about 2.5 (a little more than 300 yrs.). Half of the binaries in space may be expected to have periods between the limits of 20 and 4000 yrs.

Star	d	Parallax π	Mass sun = 1	Log period	Period years	Star	d	Parallax π	Mass sun = 1	Log period	Period years
β 733	0.72	0.100	1.0	1.43	26.7	α Cen AB . .	7.02	0.757	2.04	1.90	80.1
ζ Her (Σ 2084) . .	1.2	.112	2.1	1.54	34.5	70 Oph	6.56	.194	1.7	1.94	87.7
α CMi	3 ±	.307	1.6	1.60	40.2	Brsb 13 . . .	3.60	.140	.8	2.11	130.?
Mlb 4 AB	1.26	.140	1.1	1.62	42.2	ξ Boo	3.01	.173	1.0	2.18	151
μ Her BC	.74	.107	.90	1.63	43.0	Δ 5 (p Eri) .	9.22	.165	2.32	2.34	219
Krü 60 AB	1.36	.258	.45	1.65	44.3	o_2 Eri Bc . . .	4.52	.200	.64	2.39	248
α CMa AB	10.6	.366	3.4	1.70	50.0	η Cas	8.14	.180	1.4	2.71	508
ξ UMa AB–CD .	1.61	.145	1.4	1.78	59.9						

Spectroscopic binaries	δ Tri ξ UMa CD χ Drac	log p: −1.57 −1.56 −0.11	p: 0.0272 .027± .769	η Boo ξ UMa AB	log p: +0.13 0.26	p: 1.36 1.82

Star	d	Parallax π	d Astronomical units	Abs. magnitudes	Mass sun = 1	Log period	Period years
	″	″					
Lac 353 CD	1.2	.11?	11 ±	7.8, 8.8	1.03	1.58	38
Brs 5 (P 342y?)	1.57	.100	15.7	8.0, 8.0	1.00	1.91	82
Sh 243 AB	4.3	.174	24.8	6.5, 6.5	1.36	2.14	138
Millb 377	2.3	.115	20	10, 13	.51	2.31	204
K Tuc AB (h3423)	5.1	.11?	46 ±	5.2, 7.4	1.50	2.51	324
h 5173	9	.243	37	7.2, 13.2	.78	2.51	324
Hu 1128	5.0	.104	48	5.6, 14	.99	2.62	417
OΣ 547 AB	4.8	.100	48	9.3, 9.4	.77	2.68	480
Σ 2398	16	.294	54.4	11.1, 11.7	.55	2.83	680
Σ 1280	5.2	.100	52	8.7, 9.1	.86	2.70	500
61 Cyg (Σ 2758)	21	.300	70	8.0, 8.7	.95	2.87	740
Sh 190	14.2	.181	78.8	7.1, 10.2	.94	2.95	890
OΣ 539 AC	7.8	.095	87	7.3, 9.7	.95	3.01	1020
Σ 1321	19.4	.163	119	9.1, 9.1	.84	3.24	1740
Bo 187	39	.281	139	10.4, 13.0	.51	3.44	2700
Mlb 4 AB-C	31	.144	215	11.1, + mass 1.1	1.40	3.51	3200
μ Her A-BC	32	.105	305	3.7, + mass 0.9	2.20	3.64	4400
O_2 Eri A-BC	83	.200	415	6.0, + mass 0.64	1.38	3.92	8300
γ Lep (HV 50)	95	.149	639	4.7, 7.3	1.58	4.17	15000
Chri 2448	63.7	.095	670	8.8, 10.5	.76	4.35	22000
Lpz II 961	150	.142	1060	6.6, 12.2	.91	4.60	40000
K Tuc-Lac 353 AB-CD .	319.4	.11?	2875 ±	5.2, 7.4, 7.8, 8.8	2.53	5.02	105000
ζ Ret	310	.1?	3100 ±	5.2, 5.5	1.8	5.13	135000
OΣ 547 AB-C	330	.100	3300	9.3, 9.4, 10.2	1.11	5.28	190000
36 Oph–30 Sco AB-C . . .	730	.174	4200	6.5, 6.5, 7.8	1.89	5.32	210000
W-Ott 5811	512	.160	3210	10.2, 12.4	.56	5.41	260000
α Cen AB-C	6740	.760	8860	15.5, + mass 2.04	2.20	5.77	590000

Luyten, W. J. (Harvard College Obs., Proc. Nat. Acad. Sci., 10, 252, 257, 1930.

TABLE 817.—Masses and Absolute Magnitudes of Binary Stars

(Pitman, Astron. Journ. 39, 57, 1929.)

This paper contains a discussion of the orbits of 104 binary stars and of the relationship between stellar masses and luminosities (Eddington, M. N., March, 1924). In the following table of averages the magnitudes are visual. Values in blacker type are averages of greater weight. Six planetary nebulae give an average mass of 16.7, absolute magnitude 8.1.

	Visual binaries				Eclipsing binaries				Spectroscopic binaries			
	Trig.		Spec.		Trig.		Spec.		Trig.		Spec.	
	Mass	Mag.	Mass	Mag.	Mass	Mag.	Mass	Mag.	M. Mass	Mag.	M. Mass	Mag.
O–B0	...	...	...	...	...	...	70.1	−4.26	17.4	2.39	85.0	−4.36
	...	...	...	...	...	...	35.0	−2.68	8.7	3.96	42.5	−3.55
B1–B3	...	...	12.9	−1.14	20.87	−0.24	**15.24**	**−1.54**	15.5	.64	**9.91**	**−1.73**
	...	...	6.45	− .27	**10.44**	**− .60**	**7.62**	**− .81**	7.75	1.29	**5.22**	**− .84**
B4–B8	...	...	...	...	7.87	− .74	7.18	− .04	1.58	2.72	11.21	− .80
	...	...	...	...	3.94	1.26	**3.59**	**1.04**	.79	3.50	5.37	.25
B9–A1	2.65	2.80	**2.69**	**2.23**	4.71	−1.47	4.61	.51	1.88	.61	**2.60**	**.56**
	1.52	**3.25**	**1.51**	**2.94**	2.37	− .72	**2.36**	**1.52**	**.94**	**1.66**	**1.30**	**1.92**
A2–A6	6.76	1.54	**5.47**	**1.16**	...	...	4.29	1.30	3.20	.12	**2.52**	**1.42**
	3.15	**2.41**	**2.74**	**2.07**	...	...	2.15	2.23	1.60	1.18	**1.26**	**2.43**
A7–F2	3.57	2.25	**5.17**	**1.88**	...	...	1.17	.53	2.95	3.89	1.73	1.26
	1.59	**4.15**	**2.41**	**3.32**	...	...	.58	1.30	1.48	4.57	.86	2.00
F3–F7	**2.44**	**3.26**	**2.12**	**3.15**	2.90	4.82	2.76	2.21	2.02	2.67	**2.56**	**2.23**
	1.31	**4.50**	**1.34**	**4.54**	1.45	5.58	1.59	2.83	**1.01**	**3.64**	**1.28**	**3.02**
G0–G2	**2.11**	**3.76**	**2.22**	**3.70**	1.26	5.60	1.26	5.13	2.01	4.34	2.12	2.37
	1.06	**4.94**	**1.13**	**4.75**	.63	5.83	1.08	5.09	1.00	5.16	1.06	3.18
G3–G9	4.75	4.91	2.71	4.92	...	...	...	...	1.38	4.82	1.38	4.50
	2.28	**6.11**	**1.35**	**5.84**	...	...	...	...	.69	5.61	.69	5.41
K	1.54	6.21	**4.39**	**5.38**	...	...	...	...	...	...	...	...
	.78	**7.43**	**2.01**	**6.38**	...	...	1.74	3.94	...	...	...	...
M	.64	10.43	1.16	9.97	1.20	8.32	1.20	8.20	...	...	...	...
	.31	11.40	.51	11.02	.60	9.02	.60	8.90	...	...	...	...

TABLE 818.—Mass-Luminosity Curve

(Prepared by Doctor Shapley, 1931.)

Masses are stated as logarithms of masses in terms of the sun's mass; the magnitudes absolute bolometric.

Log mass	Abs. mag.	Log mass	Abs. mag.	Log mass	Abs. mag.
1.6	−5.5:	1.0	−2.92	0.0	+ 4.41
1.4	−4.6:	.8	−1.97	−0.2	+ 6.22
1.2	−3.84	.6	− .74	−0.4	+ 8.19
...	...	.4	+ .72	−0.6	+10.20
...	...	.2	+2.57	−0.8	+12.29

Notes added in press.—(Aitken, M. N., 92, 596, 1932.) At least one star in every 18 to 9th mag. is a close visual double; 1 in 4 or 3, a spectroscopic binary; 1495 of latter known, surely physical doubles. Orbits known for 120 pairs.

Spectrum	B	A	F	G	K	M		B	A	F	G	K	M	sun
% distribution	1.7	21.4	15.3	33.	15.6	1.4	masses	10.6	5.2	2.6	2.4	2.2	0.6	1.0

	Spectroscopic						Visual						
Periods	2.7d	7.6	14.1	30.6	102.5	3.2y	16.8y	37.1	73.	138	274	2000	5000
e	.05	.16	.22	.35	.30	.31	.43	.40	.53	.57	.62	.61	.76

TABLE 819.—Stellar Radiation Measurements (Pettit, Nicholson, 1928)

Radiometric magnitude = apparent magnitude of an Ao star which will give same radiometric deflection. Heat index = visual − radiometric magnitudes. Heat index − color index = zero for Ao star. Water-cell-absorption is fraction of radiation eliminated by water-cell expressed in magnitudes.

Giants, F5-Mo, have greater heat indices than dwarfs of same classes. Red stars deviate from black-body conditions. The radiation received at earth's surface at Mount Wilson from star in zenith of zero radiometric magnitude, 17.1×10^{-12} cal./cm²/min. Radiometric magnitude Hefner lamp at 1 meter is −20.00; International candle is 1.11 Hefner unit = −20.11; its heat index is 5.82 mag. (1900°K.).

(All measures reduced to zenith at Mount Wilson, 2 reflections from fresh silver in telescope; rock-salt window over thermocouple.)

TABLE 820.—Spectrum Classes and Temperatures

Spectral type	Observed		Temperature				
	Heat index	Water-cell absorption	Heat index λ 0.555μ	Heat index λ 0.529μ	Water-cell absorption	Color index*	Ionization†
	Mag.	Mag.					
Bo	0.05	0.20	....	....	....	23000°	20000
B5	.01	.23	....	....	....	15000	15000
Ao	.00	.26	....	....	....	11200	10000
A5	.02	.30	....	....	7500°	8600	8400
Fo	.15	.36	6750°	7300°	6200	7400	7500
F5	.30	.41	5760	6160	5450	6500	7000
gGo	.47	.50	5000	5450	4700	5500	5600
gG5	.65	.60	4550	4870	4140	4700	5000
gKo	.90	.70	4020	4300	3750	4100	4000
gK5	1.57	.93	3240	3480	3130	3300	3000
gMo	1.86	1.01	3030	3250	2980	3050	3000
gM2	2.2	1.14	2810	3000	2810	....	....
gM4	3.1	1.30	2400	2590	2550	....	....
gM6	4.2	1.46	2050	2200	2390	....	....
gM8	5.2	1.62	1780	2000	2250	....	....
Me Max	4.4	1.5	1990	2160	2350	....	....
Me Min	8.9	2.2	....	....	1830	....	....
dGo	.32	.42	5700	6100	5350	6000	....
dG5	.39	.47	5350	5750	4920	5600	....
dKo	.55	.54	4820	5100	4460	5100	....
dK5	1.10	.76	3720	3980	3550	4400	....
dMo	1.40	.87	3400	3650	3260	3400	....
dM2	2.1	1.14	2870	3060	2780	....	....

* Russell, Dugan, and Stewart, Astronomy, 2, 734, 1927. † Payne, Stellar atmospheres, 1925.
NOTE—Hottest known stars 20,000 to 30,000 °K, O type, abs. mag. −4, masses 10–80 suns, (Plaskett).

TABLE 821.—Visual and Radiometric Magnitudes and Total Radiations

Brightest stars—Visual magnitude				Brightest stars—Radiometric magnitude				Brightest stars—Total radiation reaching the solar system	
Star	Type	Vis. mag.	Rad. mag.	Star	Type	Rad. mag.	Vis. mag.	Star	Cal. cm⁻² min⁻¹ ×10¹²
Sirius	A2s	−1.58	−1.27	Betelgeuse	M2	−1.67	+0.92	Sirius	145
Canopus	F3	− .86	−1.09	Antares	M1	−1.32	+1.22	Betelgeuse	132
α Centauri	G6	+ .33	− .08	Sirius	A2s	−1.27	−1.58	Antares	96
	K4	+1.70	+ .70	Canopus	F3	−1.09	− .86	β Centauri	83
Vega	A1s	+ .14	+ .10	γ Crucis	M3	−1.0	+1.61	Canopus	77
Capella	Go	+ .21	− .38	Arcturus	Ko	− .98	+ .24	γ Crucis	69
Arcturus	Ko	+ .24	− .98	Aldebaran	K5	− .60	+1.06	Arcturus	64
Rigel	B8p	+ .34	+ .23	Capella	Go	− .38	+ .21	Achernar	51
Procyon	F3	+ .48	+ .22	o Ceti max.	M6e	− .2	+3.6	Rigel	50
Achernar	B5	+ .60	+ .60	α Centauri	G6	− .08	+ .33	Spica 33	48
β Centauri	B1	+ .86	+ .81		K4	+ .70	+1.70		

STELLAR RADIATION MEASUREMENTS

TABLE 822.—Energy Spectra of the Stars (Abbot, 1929)

Measures made with radiometer at the Coudé focus of the Mt. Wilson 100-inch reflecting telescope (arbitrary units). Astrophys. Journ., 69, 293, 1929.

Stellar energy spectrum distribution; normal scale, outside the atmosphere.

Object	Date	Place in wave lengths, microns								
		0.437	0.472	0.520	0.589	0.700	0.905	1.316	1.751	2.224
β Orionis*	13†	990	1140	584	233	89	21	...	...	...
α Lyrae	26	1355	446	334	644	287	91	77	29	...
	13	990	642	367	377	267	105	17	...	...
α Cygni	25	...	502	434	455	277	121	86	..	...
	13	...	363	267	266	297	206	172	...	...
α Aquilae	26	616	474	267	355	247	121	17	..	...
α Canis Min	13	...	139	167	277	436	149	17	...	...
α Persei	26	...	...	234	189	267	231	159	43	...
	13	...	...	184	244	228	177	73	38	...
γ Cygni	13	...	390	434	244	208	149	125	60	8
α Aurigae	25	...	28	284	388	455	369	202	119	37
Mars	13	...	...	317	366	337	256	206	41	...
Jupiter	26	...	...	134	178	238	241	95	6	...
β Ceti	25	...	...	...	155	297	263	...	35	...
	26	...	...	...	166	198	298	116	43	...
γ Aquilae	26	...	...	...	33	109	199	168	93	10
α Boötis	25	...	...	...	200	228	376	404	183	56
α Tauri	25	...	...	...	255	238	461	456	345	124
α Orionis	25	...	...	...	311	485	844	1010	597	172
β Andromedae	25	...	...	...	189	228	312	189	104	65
	26	...	...	...	155	257	177	202	104	29
β Pegasi	25	...	...	...	89	218	241	176	145	80
δ Sagittae	25	...	...	...	111	99	312	120	171	32
	26	...	...	...	144	168	170	150	128	12
α Herculis	25	...	...	...	233	406	369	417	348	83
	26	...	...	...	166	257	334	387	342	163
o Ceti	25	...	...	...	166	287	220	331	299	107
	26	...	...	...	67	337	319	396	194	61
	13	...	...	...	144	188	192	185	116	26

* Additional observations for β Orionis: 0.423μ, 505; 0.454μ, 738; 0.494μ, 827.
† The dates refer to August 25, 26, and September 13, 1928, respectively.

TABLE 823.—Stellar Temperatures, Radiation, and Diameters

Star	Absolute temperature °K	N* Unit = 10^{-11}	Parallax	Sun's diameter = 1†		
				Radiometer	Interferometer	Russell
Sun	6,000°	....	....	....	....	....
β Orionis	16,000	3.20	0″.007	20	....	28
α Lyrae	14,000	6.10	.130	2	....	3
α Can. Maj.	11,000	6.60	.370	1.2	2	....
α Can. Min.	8,000	1.24	.315	1.1	....	1.6
α Aurigae	5,800	2.20	.071	13	....	9
α Tauri	3,000	2.54	.053	70	39	....
β Pegasi	2,850	1.10	.026	94	82	....
β Orionis	2,600	7.90	.017	510	280	....
α Herculis	2,500	3.60	.007 .013	900 480	....	230

* Ratio of stellar to solar radiation outside earth's atmosphere.
† To express in kilometers, multiply by 1.42 × 10^6; to express in miles, multiply by 0.805 × 10^6.

Table 824

VARIABLE STARS—GENERAL CHARACTERISTICS

(See Russell, Dugan, and Stewart, Astronomy, 1927; Ludendorff, Stratton, Das Sternsystem, Handb. Astrophys., 6, Berlin, 1928; Payne, Stars of high luminosity, Chap. 14, 1930.)

Perhaps 5% of all stars are variable; number known, over 5000. Astronomische Gesellschaft acts as central bureau; when a variable star is confirmed it there receives a definite designation, e.g., R. T. Persei. Most recent list Astron. Nachr., 244, 82, 1931, contains 873 additional thus named variables. The Harvard College Observatory (Doctor Shapley, Cambridge, Mass.) keeps a record of variable-star data. A yearly list of stars with known periods is published by the Berlin-Babelsberg Observatory. Note added in press: 5826 in 1933 volume.

Classification

I. Periodic Variables.

(1) Eclipsing variables: Generally B and A stars. Not true variables. See Table 815.

(2) Short period: 100 to 10,000 sun's luminosity, large mass. Types B to M. Preferably F and G.

(a) Period range about $\frac{1}{2}$ day; about 10% of variables of regular period. Generally called *cluster variables;* quick rise in light, slow decline, visual range generally less than 1.5 mag.; photographic range averages 50% greater; $\frac{1}{2}$ day generally of class A; peculiar velocities average 70 km/sec.; variable radial velocity range small, proportional to range in mag. Max. of approach invariably near max. mag., max. of recession near min. mag. Galactic concentration small. Shortest period known (1932), 0.69746 days, 15 mag., range 1 mag. (8^h 19^m 38^s R. A., 18° 45′ S. dec. van Gent).

(b) Periods 1 to 32 + days; 15% of regular variables. *Cepheids.* Much like (2a) but periods 4 d, class F5; 8 d, G0; 20 d, G5. Peculiar velocities average about 12 km/sec. Galactic concentration strong. About 120 known. Long-period Cepheids are among the brightest stars known, 20,000 times brightness of sun. The following table 825 is due to Shapley, 1931.

(3) Long-period variables: Nearly all red stars 87% class M, 6% class N, 5% class S, a few G and K. *o* Ceti typical. Abs. mag. − 2.0 (Oort, 1927); periods 100 to 150 d, $M = -2.3$; 250 to 340, $M = -1.1$; > 340, $+0.3$ (Gerasimovič, 1928). Periods often irregular, proper motions small (0.03″±), radial velocities large (mean 35 km/sec.). For S Librae, 385 km/sec. Heat radiation diminishes by 1 or 2 mag. while light by 5 or so.

II. Irregular variables.

(1) R V Tauri: Resembles Cepheids somewhat irregularly. 12 known (Gerasimovič, 1929). 19 given by Ludendorff (1928).

(2) R Coronae Borealis: About 11 known. Typical R. Cor. Bor. remains often for years of 6th mag.; then may rapidly drop 6 mag. for indefinite period then returns to original mag. Ludendorff gives 11.

(3) U Geminorum (type): Normally faint but brighten up at irregular intervals to drop back to original magnitude. Some analogy to Novae. Ludendorff gives 20.

(4) T Pyxidis: Resemble Novae. Ludendorff gives 5.

TABLE 825.—The Cepheid Period-Luminosity Curve

Logarithm of period.	Mean spectrum.*	Absolute photographic magnitude.**	Absolute bolometric magnitude.
0.0	F 2.5	− 0.31	− 0.82
0.2	F 5.5	− 0.61	− 1.25
0.4	F 7.5	− 0.93	− 1.67
0.6	G 0	− 1.22	− 2.16
0.8	G 2	− 1.53	− 2.65
1.0	G 4	− 1.89	− 3.15
1.2	G 6	− 2.26	− 3.71
1.4	G 8	− 2.68	− 4.34
1.6	K 0.5	− 3.19	− 5.13
1.8	K 2.5	− 3.81	− 6.11
2.0	M 0	− 4.60	− 8.2:

* Shapley, Harvard Bull., 861, 1928. ** Shapley, Harvard Monogr., 2, 1930.

TABLE 826.—Novae

Novae (temporary stars): Between 10 to 20 brighter than the 9th app. mag. occur in a year (Bailey). Numerous in spiral nebulae. More than 80 in Andromeda nebula (Hubble); 30 per year estimated. Mean parallax of five, 0.01″; abs. mag. + 8.5 to − 3.1 (Russell). Nova Aquilae, 1918, class A before outbreak; then appears as rapidly expanding gas 1700 to 2300 km/sec.; fades to Wolf-Rayet, class O (T Coronae Bor. changed finally to gM); gaseous envelope visible 1918 to 1926, reached diameter 16″; abs. mag. + 3 to − 8.8; distant 1200 light years. Nova Persei: Diffuse cloud faint light expanding 6′ to 7′ in 7 months. Six weeks later moved 35″ to 65″—apparently due to illumination of dark nebulous matter near star by outgoing light (Russell). See Milne, Nature, 128, 715, 1931. If after outburst it has dwindled to previous magnitude but spectrum shows a higher temperature, then radius must have decreased, say 10-fold, and the density would be much greater (compare white dwarfs, Table 828).

TABLE 827.—Observed Maxima of Spectrum Lines in the Giant Sequence

(Shapley.)

Line.	Atom	Ionization potential volts.	Excitation potential volts.	Maximum.	No. of effective atoms at max. per cm² surface	Source.
4340	H	13.54	10.15	A0	4.2×10^{19}	Contour of line
				F5 *	1.9×10^{18}	Contour of line
4026	He	24.41	20.81	B1.5	1.6×10^{17}	Estimate
4481	Mg +	14.97	8.83	A3	....	Estimate
3933	Ca +	11.82	0.0	K2	2.4×10^{19}	Contour of line
				G5 *	2.4×10^{19}	Contour of line
4444	Ti +	13.6	1.16	F5	1.3×10^{17}	Line depth
4416	Fe +	16.5	2.82	F5	1.7×10^{17}	Line depth
4215	Sr +	10.98	0.0	K2	6.9×10^{17}	Line depth
4554	Ba +	9.96	0.0	M0?	....	Estimate

* Data for the supergiant sequence.

TABLE 828.—High-Density Stars. White Dwarfs

	Class	Visual abs. mag.	Density	Radius sun = 1	Mass
Sirius B	F	11.3	0.5×10^5 g/cm^3	.034	......
o_2 Eridani B...........	Ao	11.2	1.0×10^5 "	.019	......
Procyon B	..	16.	....	...	......
Van Maanen's *	F	14.3	4×10^5	.007	......

* Smallest star known, about the size of the earth.

TABLE 829.—Low-Density Stars. Giants

	Class	Visual abs. mag.	Density	Radius sun = 1	Mass sun = 1
α Scorpii A...........	cMo	— 4.0	3×10^{-7}	480	(30)
α Orionis	cMo	— 2.9	6×10^{-7}	290	(15)
β Pegasi	gM5	— 1.4	2×10^{-6}	170	(9)
α Tauri	gK5	— 0.1	2×10^{-5}	60	(4)

(Taken by permission from Russell, Dugan, and Stewart, Astronomy, Ginn & Co., 1927.)

TABLE 830.—High-Temperature Stars. High-Luminosity Stars

(Plaskett, M. N. 90, 616, 1930. Payne, Stars of high luminosity, 1930. Pearce, Pub. Dom. Astron. Obs., 3, 302, 1926.)

Draper Catalogue, 0.1% O; 0.3% Bo to B2; 1% B3-B5. Stars of highest temperature, greatest mass, highest luminosity, greatest distance from sun. Masses 5, O type, 43 × sun's; 10, Bo to B2, 15 × sun's; 12, B3, B5, 6 × sun's.

Type.	Temp.	Surface brightness.	$M_v - M_b$	M_v	Density.
O5	35,000° K.	— 4.15 M	3.61 M	...	...
O6	33,000	— 4.10	3.41	...	...
O7	31,000	— 4.03	3.20	...	...
				— 3.84	.049
O8	29,000	— 3.96	2.98	...	...
O9	27,000	— 3.88	2.76	...	...
Bo	25,000	— 3.78	2.52	— 3.16	...
B1	22,000	— 3.61	2.13	— 2.72	.056
B2	19,000	— 3.38	1.73	— 2.59	...
B3	16,000	— 3.08	1.28	— 1.44	.071
B5	14,000	— 2.80	0.98	— 1.86	...

NOTE.—See Russell, The Constitution of the Stars, Science, 77, 65, 1933.

TABLE 831.—Properties and Classification of Star Clusters

Star clusters fall into two distinctly different types:

Globular: Typical, Messier 13; open, Messier 4; elongated, Messier 19. Have strong central condensations, rich in faint stars. Scattered widely in latitude, restricted in longitude. Many variables—nearly 900 in 45 clusters. Radial velocities > 100 km/sec. All distant > 10,000, $\frac{1}{3}$ > 100,000 light-years. Very few new ones found—about 103 known. Very definitely part of galaxy. Although concentrated towards its plane, only 2 within 4° of it (cloud obstruction probably). Diameters about 35 parsecs. Many stars, tens and hundreds of thousands. Many giants and supergiants. Max. luminosity about — 2.5.

Galactic: Very varied: rich, M 11; irregular, M 35; nebulous, Pleiades, M 16; accidental, M 103. Almost exclusively in Milky Way, all longitudes; apparently no variables. Radial velocities rarely > 40 km/sec., generally less. Almost all < 4000 light-years distant. Almost exclusively in galactic region devoid of globulars. Tens and hundreds, rarely thousands of stars. Hyades type, yellow stars as dominant as A type. Pleiades type, almost all B's and A's, on Russell's main branch.

TABLE 832.—Distribution of Open Star Clusters

(Trumpler, Bull. Lick Obs., no. 420, 1930. Contains classification in diameters, distances, and distribution of 334 open clusters.)

The plane of symmetry of open clusters is inclined 2°.3 to the adopted galactic plane. Its pole lies at R. A. $12^h\,50^m$. Dec. 27°.7 (1900). Forms much flattened disklike system 1000 parsecs thick, diameter 10,000 parsecs.

Lat.	In galactic latitude. Long. 90°-270°.	Long. 270°-90°.	Total.	In plane ⊥ to plane of concentration. Mean distance parsecs.	No. per layer 100 parsecs thick.
— 90° to — 30°	0	1	1	— 850	2
— 30 — 20	3	0	3	— 750	0
— 20 — 15	5	0	5	— 650	1
— 15 — 10	8	4	12	— 550	2
— 10 — 8	4	2	6	— 450	1
— 8 — 6	3	8	11	— 350	5
— 6 — 4	12	16	28	— 250	10
— 4 — 2	19	38	57	— 150	38
— 2 0	34	28	62	— 50	113
0 + 2	34	27	61	+ 50	106
+ 2 + 4	27	10	37	+ 150	29
+ 4 + 6	12	2	14	+ 250	11
+ 6 + 8	9	5	14	+ 350	6
+ 8 + 10	2	1	3	+ 450	6
+ 10 + 15	7	3	10	+ 550	1
+ 15 + 20	4	1	5	+ 650	1
+ 20 + 30	1	1	2	+ 750	1
+ 30 + 90	3	0	3	+ 750	1
Total	187	147	334	Total	334

In galactic longitude.

Long.	No.	Long.	No.
0°-40°	12	160°-200°	46
40 -80	34	200 -240	41
80 -120	40	240 -280	51
120 -160	28	280 -320	41
		320 -360	41

In galactic plane.

Ring limits parsecs.	No. of clusters.	Density per 10^6 parsecs².
0-1000	88	28
1000-2000	108	12
2000-3000	77	5
3000-4000	38 (48)	2
4000-5000	16 (36)	1
> 5000	7	

TABLE 833.—Globular Star Clusters

Table contains those distant greater than 40,000 and less than 10,000 parsecs. For complete list see Shapley, Star clusters, p. 224, McGraw-Hill, 1930.

1 kiloparsec = 31 × 10^{15} km = 3 × 10^3 light-years. Proper motions:
M13, R.A. +0.0005″, dec. +0.0008; M56, −0.0013, +0.0066; M2, +0.0082, +0.0026; Van Maanen, 1927

N. G. C.	R. A. 1900 h	m	Dec. 1900 °	′	Galactic Long. °	Galactic Lat. °	Angular diameter ′	No. variables	Distance kiloparsecs
6397 (Δ366).....	17	32.7	−53	37	304.5	−12.5	19.0	2	5.65
104 (47 Tuc.)...	0	19.6	−72	38	272	−45	23	7	6.8
5139 (ω Cen.)....	13	20.8	−46	47	277	+15	23	132	6.8
6656 (M22)......	18	30.3	−24	0	337	− 9	17.3	21	6.8
6121 (M4).......	16	17.5	−26	17	319	+15	14.0	33	7.2
6752 (Δ295).....	19	2.0	−60	8	303	−26.5	13.3	1	8.4
6809 (M55)......	19	33.7	−31	10	336	−25	10.0	2	8.8
6541 (Δ473).....	18	.8	−43	44	317	−12	6.3	1	8.9
3201 (Δ445).....	10	13.5	−45	54	244	+ 9	7.7	61	9.2
4372............	12	20.1	−72	7	269	−10	12.0	..	9.6
6205 (M13)......	16	38.1	+36	39	27	+40	10.0	7	10.3
6342............	17	15.3	−19	29	333	+ 8	.5	..	40
6528............	17	58.4	−30	4	328.5	− 5	.5	..	44.4
6325............	17	11.9	−23	38	327.5	+ 6	.7	..	46
6864 (M75)......	20	.2	−22	12	347	−27	1.9	11	48.5
6356............	17	17.8	−17	43	334	+ 9	1.7	..	50
6440............	17	43	−20	20	335	+ 2	.7	..	50
6453............	17	44.7	−34	36	322.5	− 5.5	.7	..	50
6517............	17	56.4	− 8	57	347	+ 6	.4	..	50
7006............	20	56.8	+15	48	32	−21	1.1	11	56.8

TABLE 834.—Galactic Star Clusters

Selected as having the best determined distances from list of 248 clusters in Shapley, Star clusters, p. 228, McGraw-Hill, 1930.

1 kiloparsec = 31 × 10^{15} km = 3 × 10^3 light-years

N. G. C.	R. A. 1900 h	m	Dec. 1900 °	′	Galactic Long. °	Galactic Lat. °	Diameter Ang. ′	Diameter Linear kps.	No. stars	Distance kiloparsecs
663........	1	39.2	+60	44	98	− 0.4	11	2.5	80	0.79
869........	2	12	+56	41	102.5	− 3.1	36	26.3	..	....
884........	2	15.4	+56	39	103	− 3.1	36	26.3	..	2.51
Pleiades....	3	41	+23	48	134.5	−22.3	..	10:	..	.15
Hyades....	4	14	+15	23	147	−22.6	..	10:	..	.04
1960.......	5	29.5	+34	4	143	+ 2.4	12	4	60	1.16
2099.......	5	45.8	+32	31	145	+ 4.5	20	8.4	150	1.45
2632.......	8	34.3	+20	20	173.5	+34	..	...	..	.18
Mel 111....	12	20	+26	40	200	+85.4	..	...	..	.1
6705.......	18	45.7	− 6	23	355	− 4.2	10	3.6	200	1.25
7654.......	23	19.8	+61	3	80.5	+ .5	12	4.1	120	1.17

TABLE 835.—Classification of Nebulae

(Hubble, Astrophys. Journ., 64, 321, 1926; Contr. Mt. Wilson Obs., no. 324.)

		Symbol	e. g.
I Galactic nebulae—	A Planetaries	P	N.G.C. 7662
	B Diffuse	D	
	(1) Predominantly luminous	DL	N.G.C. 6618
	(2) " obscure	DO	Barnard 92
	(3) Conspicuously mixed	DLO	N.G.C. 7023
II Extra-galactic nebulae—	A Regular		
	(1) Elliptical. 1 to 7 shows ellipticity	EN	N.G.C. 3379 E0; " 221 E2; " 4611 E5; " 2117 E7
	(2) Spirals		
	(a) Normal spirals	S	
	(1) Early	Sa	N.G.C. 4594
	(2) Intermediate	Sb	" 2841
	(3) Late	Sc	" 5457
	(b) Barred spirals	SB	
	(1) Early	SBa	N.G.C. 2859
	(2) Intermediate	SBc	" 3351
	(3) Late	SBc	" 7479
	B Irregular	Irr	N.G.C. 4449

Extra-galactic nebulae too faint to be classified, "Q"

TABLE 836a.—Galactic Nebulae

(Russell, Dugan, and Stewart, Astronomy, 1927; Russell, Atkinson, Nature, 127, 661, 1931.)

Dark nebulae: Detected by obscuration of stars.

Diffuse ": Irregular of outline and shape—probably owing their detection to reflected light from nearby stars.

Planetary ": Roundish, sharply defined, almost always with a central star; less than 150 known. Gerasimovič (1929) gives mean distance about 790 parsecs. The largest parallax is for N.G.C. 7283 in Aquarius, 12′ in diameter. Russell gives mean parallax 0.008″, mean diameter 54″. Nuclear star absolute mag. + 7 to + 8 (Russell, Menzel), + 5 (Gerasimovič). Classes O, Oe (ordinary isolated O type stars abs. mag. −4). Proper motion, mean of 9, 0.022″; av. radial veloc. ±37 km/sec.; 6 > 100 km/sec.

Zanstra gives temperatures 30,000 to 100,000° K. for 20 of these objects; radius perhaps 1/43 our sun's; density 100,000 g/cm², possibly, 10^6 or 10^7 g/cm². Apparently upper end of a white dwarf sequence probably parallel to main dwarf sequence, viz.:

	M_v	Sp.		M_v	
Planetary nuclei	4	= O	Sirius B	10	A5
o Ceti B	6	BSe	Van Maanen's	14.5	F
o_2 Eridani B	11	AO	Wolf 489	13	G

Observed velocity of rotation 1.4 to 18, av. value 5.3 km/sec. at an apparent distance of 5.7″ from center. Period of rotation must be large, 4,000 to 15,000 years.

TABLE 836b.—Data on Six Planetary Nebulae

(Van Maanen, Proc. Nat. Acad. Sci., 4, 394, 1918.)

N.G.C.	Parallax	Magnitude App. m	Magnitude Abs. M	Diameter Angular	Diameter Astr. units	Diameter Light-years
2392	+0.022	+10.0	+ 6.7	46″	2100	0.03
6720	+ .008	+14.7	+ 9.2	80	10000	.16
6804	+ .022	+13.4	+10.1	32	1450	.02
6905	+ .015	+14.5	+10.4	47	3100	.05
7008	+ .016	+12.8	+ 8.8	95	5900	.09
7662	+ .023	+12.9	+ 9.7	31	1350	.02

Mean abs. mag. +9.1. Mean radial velocity 29 km/sec. (Campbell, Moore, Proc. Nat. Acad. Sci., 1, 496, 1915.) (Diameter Neptune = 60 astr. units.)

TABLE 837.—Diffuse Galactic Nebulae, Dimensions

(Trumpler, Proc. Astron. Soc. Pacific 43, 255, 1931.)

	Orion neb.	Pleiades	N.G.C. 2237	6514	6523 (Mes. 8)	6611 (Mes. 16)
Distance parsecs	540	150	1340	980	1090	2050
Diameter (′)	50′	360′	60′	23′	35 × 55′	20′
" parsecs	8	16	23	6.5	11 × 17	12

TABLE 838.—Nongalactic Nebulae

(Hubble, Astrophys. Journ., 64, 1926.)

Some 400 considered. Distribution of magnitudes appears uniform throughout sequence. For each stage in the sequence the total magnitude (M_T) is related to the max. diameter (d) by the formula: $M_T = C - 5 \log d$. When minor diameter is used, C approx. constant throughout sequence ($C = 10.1$). Mean absolute visual magnitude -15.2. The statistical expression for distance in parsecs is $\log D = 4.04 + 0.2\ M_T$. *Masses* appear to be of the order of $2.6 \times 10^8 \times$ our sun's. Apparently nebulae as far as measured are distributed uniformly in space, one to 10^{17} parsecs^3 or 1.5×10^{-31} in C.G.S. units.

Corresponding radius of curvature of the finite universe of general relativity is of order of 2.7×10^{10} parsecs, about 600 times the distance at which normal nebulae can be detected with the Mt. Wilson 100-inch reflector.

TABLE 839.—The Magellanic Clouds and N.G.C. 6822, Dimensions

(Hubble, Astrophys. Journ., 62, 409, 1925.)

		Large cloud	Small cloud	N.G.C. 6822	
Angular size:	Total	7.2°×7.2°*	3.6°×3.6°	20′×10′	
	Core	3.6°×1.2°	1.8°×0.9°	8′×3′	
App. luminosity:	Total	1.2	2.0‡	9.0	phtg. mags.
	Core	1.9	2.7	9.7	" "
Surface brightness:	Core	21.0	21.0	22.1	mag./(″)^2
Distance		34,500*	31,600†	214,000	parsecs
Linear dimensions:	Total	4,300§	2,000†	1250×625	"
	Core	2150×715	1100×500	500×190	"
Volume:	Total	4.2×10^{10}	4.2×10^9	3.8×10^8	(parsecs)^3
	Core	9.2×10^8	2.3×10^8	1.7×10^7	"
Absolute luminosity:	Total	−16.5§	−15.5	−12.7	phtg. mag.
	Core	−15.8	−14.8	−12.0	" "
Mean density:	Total	−10.0	8.5	8.8	abs. mag./parsecs^3
	Core	6.6	6.1	6.1	" "

* Harvard Coll. Obs. Circ. no. 268. † loc. cit. 255. ‡ loc. cit. 260. § Harvard Coll. Obs. Bull. no. 816.

MAGNITUDES, RADIAL VELOCITIES, AND DISTANCES OF EXTERNAL GALAXIES

The following table is due to Shapley (Proc. Nat. Acad. Sci., 15, 565, 1929). The velocities (mainly Slipher data) are from Hubble (loc. cit., 15, 169, 1929); the velocities are also given corrected for the sun's motion towards the apex A, 277°, D, +36°, and a velocity of 280 km/sec. (Hubble, loc. cit.), i.e., corrected for "galactic rotation". Color indices are not very reliable but the mean values for various groups serve to indicate negligible absorption of light in space. Mean difference phtg.-vis. mag., +0.23; Hubble's 7619, the faintest, fastest, probably most remote, shows the largest color index, +2.8.

Class	N.G.C.	R. A. 1900 h m	Dec. 1900 ° ′	Radial velocity km/sec.	v_0 km/sec.	Apparent photographic magnitude mean (Harvard)	Visual mag. Holetschek corrected	Distance in megaparsecs (Hubble)
Peculiar..	205	0 35	+41 8	− 300	− 195	11.2	10.0	
E2......	221	0 37	+40 19	− 185	− 85	8.7	8.8	0.275
Sb.......	224	0 37	+40 43	− 220	− 120	6.0	5.0	.275
Sc.......	278	0 46	+47 1	+ 650	+ 760	11.7	12.0	
E0......	404	1 4	+35 11	− 25	+ 40	11.6	11.1	
E4......	584	1 26	− 7 23	+1800	+1725	11.8	10.9	
Sc.......	598	1 28	+29 8	− 70	− 40	9.0	7.0	.263
SBa.....	936	2 23	− 1 36	+1300	+1185	11.2	11.1	
SBa.....	1023	2 34	+38 38	+ 300	+ 310	11.2	10.2	
Sb.......	1068	2 38	− 0 26	+ 920	+ 795	9.8	9.1	1.0
E4......	1700	4 52	− 5 1	+ 800	+ 580	12.1	12.5	
	2681	8 46	+51 41	+ 700	+ 710	11.3	10.7	
Sc.......	2683	8 46	+33 48	+ 400	+ 335	11.3	9.9	
Sb.......	2841	9 15	+51 24	+ 600	+ 620	10.5	9.4	
Sb.......	3031	9 47	+69 32	− 30	+ 75	8.5	8.3	.9
Irreg.....	3034	9 48	+70 9	+ 290	+ 395	8.6	9.0	
E7......	3115	10 0	− 7 14	+ 600	+ 495	9.9	9.5	
Sa.......	3368	10 41	+12 20	+ 940	+ 870	9.8	10.0	
E0......	3379	10 43	+13 6	+ 810	+ 745	10.2	9.4	
Sb.......	3489	10 55	+14 26	+ 600	+ 550	10.5	11.2	
Sc.......	3521	11 1	+ 0 30	+ 730	+ 635	9.8	10.1	
Sb.......	3623	11 14	+13 39	+ 800	+ 765	9.8	9.9	
Sb.......	3627	11 15	+13 33	+ 650	+ 590	10.0	9.1	.9
E7......	4111	12 2	+43 38	+ 800	+ 895	11.0	10.1	
Sb.......	4151	12 5	+39 58	+ 960	+1050	10.9	12.0	1.7
Irreg.....	4214	12 11	+36 53	+ 300	+ 385	10.6	11.3	.8
Sb.......	4258	12 14	+47 52	+ 500	+ 455	9.8	8.7	1.4
E4......	*4382	12 20	+18 45	+ 500	+ 570	9.7	10.0	
Irreg.....	4449	12 23	+44 39	+ 200	+ 230	9.5	9.5	.63
E1......	*4472	12 25	+ 8 33	+ 850	+ 870	9.1	8.8	
E0......	*4486	12 26	+12 57	+ 800	+ 835	9.2	9.7	
Sa.......	*4526	12 29	+ 8 15	+ 580	+ 600	10.3	11.1	
Sb.......	4565	12 31	+26 33	+1100	+1175	10.4	11.0	
Sa.......	4594	12 35	−11 4	+1140	+1115	9.4	9.1	
E2......	*4649	12 39	+12 6	+1090	+1130	9.8	9.5	
Sb.......	4736	12 46	+41 40	+ 290	+ 410	8.8	8.4	.5
Sb.......	4826	12 52	+22 13	+ 150	+ 230	9.3	9.0	.9
Sc.......	5005	13 6	+37 35	+ 900	+1030	10.6	11.1	
Sb.......	5055	13 11	+42 33	+ 450	+ 590	10.0	9.6	1.1
Sc.......	5194	13 26	+47 43	+ 270	+ 450	8.3	7.4	.5
	5195	13 26	+47 47	+ 240	+ 410	10.5	8.9	
Sc.......	5236	13 31	−29 21	+ 500	+ 470	8.8	10.4	.9
Sc.......	5457	14 0	+54 49	+ 200	+ 385	10.2	9.9	.45
Sa.......	5866	15 4	+56 9	+ 650	+ 865	11.2	11.7	
	6822	19 39	−15 0	− 130	+ 35	11.3		.214
Sb.......	7331	22 33	+33 54	+ 500	+ 685	10.1	10.4	1.1
E3......	7619	23 15	+ 7 39	+3780	+3910	14.6	11.8	

TABLE 841.—Extra-Galactic Nebulae, High Velocities

(Hubble, Humason, Astrophys. Journ., 74, 43, 1931.)

Velocity (km/sec.) = (Distance in parsecs)/1790

Object.	Distance.	Mean velocity.	Notes.
Virgo cluster	1.8 million parsecs	890 km/sec.	Several nebulae, 12° × 11°
Pegasus "	7.25	3800	100 ± nebulae
Pisces group	7.	4630	25 "
Cancer cluster ...	9.	4800	150 "
Perseus " ...	11.	5200	500 "
Coma " ...	13.8	7360	800 "
Urs. Maj. " ...	21.4	11800	300 "
Leo " ...	32.	19600	300 "

Extra-galactic nebulae.—(Analysis of 900 plates with 60- and 100-in. Mt. Wilson reflectors, Hubble, Science, 75, 24, 1931.) (1) None found in low galactic latitudes; avoidance zone irregular, 10° to 40° width—apparently due to known obscuring clouds in Taurus, Cassiopeia, Ophiuchus, etc. Inclined belt of bright B stars and diffuse nebulosity reaches highest latitude in Taurus and Ophiuchus. (2) Avoidance zone bordered by partial obscuration to − 40° in general direction of center of galactic system (long. 330° to 340°); very limited in opposite direction (except in Taurus) long. 140°, lat. − 35° to − 40°. (3) Lat. > 40° (and in lower lat. towards anti-center) nebulae approx. uniform distribution log number per sq., degree = 2.375. Variation with exposure time indicates uniform distribution also in depth. (4) Appreciable absorption of light in extra-galactic space appears inadmissible. (5) Mean abs. phtg. mag. − 13.8. Density one neb./6×10^{-31} parsec^3. Mean mass 5×10^8 sun's. Mean density in observable space 5×10^{-31} g/cm^3. (6) It may be hazarded that clustered nebulae (in 1 hr. plates) may be expected one per square degree.

TABLE 842.—Rotation of Stars

Values derived for the components, in the line of sight, of the equatorial velocities of rotation for single stars, 0 to 250 km/sec. Assuming that the axes of the stars having the largest rotational velocities are at right angles to the line of sight, it appears that these stars are still stable. "Our analysis of the spectra of giants and dwarfs shows that all single stars belonging to the later spectrum classes show little rotation. On the other hand, a number of spectroscopic binaries of late type, such as W Urs. Maj. have a very rapid rotation. In fact, Adams and Joy have in a number of cases successfully predicted that stars of spectrum classes F or G showing diffuse lines are close spectroscopic binaries. It is probable that we have here a real difference in behavior: in the early spectrum types rapid axial rotation is observed in single stars about as frequently as in spectroscopic binaries; while in the later types rapid rotation occurs only in close binaries. This may have a bearing on the problem of the origin of double stars. (Struve-Elrey, M. N. 26, 91, 663, 1931.)

TABLE 843.—The Galaxy, its Center and Rotation

The center of the galaxy lies apparently among the dense clouds in Sagittarius 40,000 light-years (13,000 parsecs). About this center the sun revolves with a period of about 250,000,000 years, an orbital speed of 200–300 km/sec. Amount of matter within sun's orbit must have mass about 200 billion times our sun's. In following table based partly on Redman, M.N. 92, 113, 1931, r = mean distance in parsecs from center of objects. A = about .017 km/sec./parsec. l_0 longitude galactic center. The sun is about +33 parsecs from galactic plane (Gerasimovič, Luyten, Proc. Nat. Acad. Sci., 1927).

Type	m	Approx. distance	No. objects	rA	l_0	Source
(1) O-B2	3.98	250	78	2.8	290°	Plaskett, Pearce
(2) B3-B5	4.64	135	241	1.0	300	" "
(3) B3-B5	6.60	330	222	3.2	346	" "
(4) A-G, μ < ".020>	5.3	180	122	7	345	Oort, B.A.N., 1927
(5) A-G, μ < ".020	6.4	210	88	10	337	" " "
(6) B8-B9	5.1	160	250	2.1	334	Lindblad, M.N., 1930
(7) F-K, μ < ".040	5.4	190	714	3.8	346	" " "
(8) A, μ < ".040	5.3	160	304	5.0	319	" " "
(9) K	7.3	230	392	1.9	17	Redman, loc. cit., 1931
(10) O-B5	...	...	790	4.3	321	Pearce, 1931
(11) Interstellar Ca. }	...	...	103	5.3*	325	Gerasimovič, Struve }
(12) Same stars }	...	...	103	12.0*	330	Astrophys. Journ., 1929 }

* These values seem consistent on the supposition that the Ca is more or less evenly distributed between the stars and us, so that r for Ca should be ½ that for the stars.

Lindblad (Scientia, 61, 325, 1932) gives a more recent summary of various workers. With Plaskett's A = +0.0155 km/sec./parsec, time of revolution = 200,000,000 years; l_0 = 327°. With a linear speed of 275 km/sec. our distance to center is 9,400 parsecs (about 30,000 light-years). Total mass of stellar system = 16 × 10^{10} solar masses.

TABLE 844.—Transmission of Light Across Space; Theoretical

(Russell, Proc. Nat. Acad. Sci., 8, 115, 1922; Nature, 110, 81, 1922.)

Let radius of particle = r', density, ρ, (random distribution); quantity of matter per unit vol. = d. The extinction of a beam of light will be e stellar magnitudes per unit distance where $e = 0.814\, qd/\rho r$. q is a numerical factor independent of physical units, taking account of complications when $2r$ becomes near the wave length, λ, of the light; when $2r = 2$ or 3λ, q = sensibly unity. q increases for small particles to a max. 2.56, when circumference = $1.12 \times \lambda$; then rapidly decreases, = nearly $(14/3) \times 2\pi r/\lambda^4$ for particles less than 1/2 this diameter. q/r is max. 2.42, when circumference = λ.

Clouds, same mean density, d, opacity reaches sharp max. when particles of this size, at the same time becomes selective $(1/\lambda^4)$. Visual max. when $r = 0.086\rho$. A cloud of this size dust, (density 2.7), absorbs 1 magnitude if 1/86 mg./cm² regardless of cross section. If 1/2 this or smaller, selective absorption almost as complete as for a gas. Best size particles for opaqueness also best for light pressure.

Rayleigh's formula for gas is $I = I_0\, e^{-k}$

$$k = \frac{32\pi^3}{3N}\frac{(n-1)}{\lambda^4}$$ where n is the index of refraction, N, Loschmidt's number.

TABLE 845.—Transmission of Light Across Space; Observed Estimates

Kapteyn, 1904	0.0016 mag./parsec	Van Rhijn, 1928	0.000035* mag./parsec
Seeliger, 1911	.0003 "	Shalen, 1929	.0005 "
Halm, 1917	.0030 "	Lundmark, 1925	.00000007 "
		Shapley, 1929	.000000007 "

* Equivalent to 4.7×10^{-14} g/cm². Bull. Astron. Soc. of Netherlands, 4, 123, 1928. Eddington computed 0.00007 per 100 parsecs as scattering coefficient. For Ca Gerasimovič, 1929, obtained 1.1×10^{-22} as the scattering coefficient.

Absorption and space reddening in the Galaxy as shown by the colors of globular clusters. Stebbins, Proc. Nat. Acad. Sci. 19, 222, 1933.

TABLE 846.—Amount of Matter in Interstellar Space

(Eddington, Proc. Roy. Soc., A3, 424, 1926. Note also Table 848.)

Whether or not matter exists in space is important in estimating absolute magnitudes (Cepheids), and, as a resisting medium, for its dynamical effects.

Density at average point, 10^{-24} g/cm^3 (Eddington, dynamical reasons, star velocities).

(Gerasimovič, Struve, Gaseous substratum of galaxy, Astrophys. Journ., 69, 7, 1929.)

Interstellar density of Ca probably about $\rho_{Ca} = 3.6 \times 10^{-32}$ g/cm^3

For all gases 10^{-26} "

Assuming matter of about atomic weight 20, doubly ionized so that there will be about one free electron per cm, then

Free path for ions, roughly 10^8 km, duration 1 year.

Free path for electrons, roughly 5.2×10^8 km, duration 10 days.

An ion encounters and deflects an electron once in 5 days.

Central density of typical diffuse nebula, estimated, 10^{-20} g/cm^3. Hubble (Astrophys. Journ., 1926) estimates if all matter within 100 light-years uniformly distributed, density of order 10^{-31} g/cm^3. Eddington (Nature, 128, 702, 1931), 10^{79} electrons and protons in universe.

TABLE 847.—Radii of Curvature of Space

Radius of curvature of the finite universe of general relativity is of the order of 2.7×10^{10} parsecs (Hubble, Astrophys. Journ., 64, 1926).

Radius of Curvature of de Sitterian space time:

460 stars	3.63×10^{11} astr. units	$= 5.74 \times 10^6$ light-years	$= 1.8 \times 10^6$ parsecs
29 Cepheids	3.0 "	"	"
35 O stars	3.2 "	"	"

(Silberstein, Nature, 9, 50, 1930.)

TABLE 848.—Interstellar Gases (Calcium, Sodium)

Since excited atoms are exceedingly rare, the only strong absorption lines will be the principal lines. Na, Ca, and Ca + have principal lines in the observable spectrum. If we take a 12000° K. temperature for the interstellar medium, ionization potential may be taken as 20 volts $= \psi_0$. For electrons of ionization potential ψ the fraction ionized is $x/(1-x) = e^{(\psi-\psi_0)/RT}$. For Na, $\psi = 5.1$ v. and 30.35 v., $T = 12000$, $RT = 10.3$ v. whence

$$x/(1-x) = 2 \times 10^6 \text{ for 1st ionization; } 10^{-6} \text{ for 2nd ionization.}$$

Thus the Na + (which is undetectable) is but one part in 2,000,000 of Na. For Ca with ionization potential 6.1 and 11.8 v. we have nearly all Ca as Ca + +, but one part in 3000 of Ca +, one in 2×10^9 of Ca.

Certain brighter stars show these lines of Ca (fewer those of Na), which when corrected for solar motion indicate a stationary (relative to sun) absorber, whereas other lines indicate a definite radial velocity for the star (Plaskett). Struve gives the following table indicating definitely the increase of this absorption with the distance:

Parsecs	Stars	K intensity	Parsecs	Stars	K intensity
0-100 parsecs	22 stars	K intensity 2.1	400-600 parsecs	30 stars	K intensity 4.2
100-200	101	2.2	600-800	26	4.6
200-300	62	3.1	800	33	3.1
300-400	47	3.3			

Note.—Max. intensity K corresponds closely to outside boundary of local cluster (He B stars). The interstellar Ca apparently shares in the rotation of the galaxy (see Table 843).

Note added 1933.—Plaskett, Pearce consider best value of interstellar density of matter as 10^{-25} g/cm^3.

TABLE 849.—Temperature of Interstellar Space

(Eddington, Proc. Roy. Soc., A3, 424, 1926.)

Total light from stars equivalent to 1000 1st (visual) mag. or heat from about 2000 (bolometric) 1st mag. stars. Star abs. mag. 1 radiates $36 \times$ sun $= 1.37 \times 10^{35}$ erg/sec. At std. distance 10 parsecs (3.08×10^{19} cm) gives flow of 1.15×10^{-5} erg/cm²/sec. Energy density due to star app. bolometric mag. 1.0, is 3.8×10^{-16} erg/cm³ or energy of starlight $= 7.7 \times 10^{-13}$ erg/cm³. The effective temperature of space from Stefan's law is 3°.2 K.

In a region away from prepondering influence of a star a *black* body will take up a temperature 3°.2 K.; then its radiation will balance that which it absorbs. But if the receiving matter be a strongly selectively absorbing gas, higher temperatures may result. See Fabry., Astrophys. Journ., 45, 264. Then the temperature will be governed by 4 considerations: (1) Line absorption (excitation of atoms); energy held about 10^{-8} sec. and then lost by reradiation. An atom meets an electron only once in 5 days. So negligible chance (10^{-10}) of thermal agitation by an encounter. (2) Scattering of free electrons; retards an electron 1 mm/sec./yr.—not cumulative and negligible. (3) Continuous absorption during encounters of electrons with atoms (orbit switches). (4) Photoelectric effect (ionization of atoms). Velocity depends on quality and not intensity of radiation. Forms an electron gas with temperature determined by the mean energy of expulsion. The temperature defined by the mean molecular speed is of the order 10,000° K.*

The temperature of the electron gas will be the same in space as close to the star. The rate of production of electrons but not their speed will be diminished. The heat of the electrons will be continually renewed and the atoms will gradually be brought to the same temperature. This high temperature is a typical quantum effect.

* 15,000° K. is considered a better value from more recent data. Plaskett, Pearce, The problems of the diffuse matter in the galaxy, Publ. Dominion Astrophys. Obs., 5, 167, 1923.

TABLE 850.—Matter and Energy

(Donnan, Nature, 128, 290, 1931. Dushman, Gen. Elec. Rev., 33, 327, 1930; Eddington, Nature, May 1, 1926.)

Jeans proposed the annihilation and transformation of an electron and a proton into radiation to account for the immense output of radiation from the stars. Einstein's special relativity theory gives as the energy corresponding to a mass of m grams of matter mc^2 ergs ($c =$ velocity of light). If $E =$ energy in ergs, then this transformed to matter $= E/c^2$ grams. The mass of a proton + electron $= 6.06 \times 10^{23}$ g. Applying Einstein's development of Planck's quantum theory, then the coalescence of a proton and electron produces one quantum of monochromatic radiation (photon); and since $mc^2 = h\nu$, $\nu = 2.2 \times 10^{23}$ or $\lambda = 1.3 \times 10^{-13}$ cm. Formerly such short waves were not known but the discovery of cosmic rays shows their possibility.

Now the reaction $P + E \rightleftarrows$ radiation can occur only under unusual conditions. Imagine a proton-electron gas, only photons of $\nu \geqq 2.2 \times 10^{23}$ could change into a matter pair. Donnan shows that the black-body temperature of a *hohlraum* radiation necessary would be 2.2×10^{12} °K. By another method (equation for variation with the temperature of the

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equilibrium constant of an ideal gas reaction, $d \cdot \log K/dT = Q/RT^2$) he derives a T of 10^{12} °K. Milne yields another solution. If $n =$ no. of protons (electrons) present per cm^3 at statistical equilibrium, then $n = 0.96 \times 10^{18}\ T^{\frac{1}{2}} \times 10^{-(2.35\times 10^{12})/T}$.

T	n/cm^3	$\rho_m\ (g/cm^3)$	$\rho_r\ (g/cm^3)$
10^{10}	10^{-202}	1.65×10^{-226}	0.85×10^{5}
10^{11}	10^{11}	1.65×10^{-13}	0.85×10^{9}
10^{12}	10^{67}	1.34×10^{10}	0.85×10^{13}

We have the following picture: As T rises, molecules will be ionized and finally all dissociated to atoms; then the atoms become ionized with finally a proton-electron gas. At some very high temperature $P + E \rightarrow$ radiation sets in. Milne's equation shows that at $T = 10^{10}$ this reaction is practically complete. As T rises yet higher the birth of matter will commence and we see that $T = 10^{12}$, the equilibrium density of matter becomes equal to 1.34×10^{10} g/cm^3. $T = 10^{12}$ corresponds to enormous densities for both matter and radiation. Enormous voltages (9×10^8 volts) may give the attainment of such reactions.

Compton effect.—X rays are supposed to consist of streams of energy quanta. While each quantum carries the energy equivalent to $h\nu$, one may also specify each of these photons (light units) by the momentum which, according to the theory of quanta, is equal to $h\nu/c$. When this photon collides with a free or loosely bound electron there is an interchange of both energy and momentum in accordance with the laws of conservation of energy and of momentum. Consequently the photon suffers a recoil in one direction with loss of momentum, while the electron moves off in another direction with added momentum. The decrease in momentum of the scattered X-ray photon corresponds to an increase in wave length. (Dushman, Gen. Elec. Rev., 33, 334, 1930.)

De Broglie phase waves.—De Broglie was led to the conception that associated with a particle of mass m_0 (rest mass, zero velocity) and velocity v, there is a wave motion of wave length given by

$$\lambda = h\sqrt{1 - v^2/c^2}/m_0 v = h/m_0 v$$

for small values of v; c is the velocity of light. The theory of relativity gives as the total energy, E, of a particle of mass m_0

$$E = m_0 c^2/\sqrt{1 - v^2/c^2} = mc^2$$

with m the mass for velocity v. According to the quantum theory, the frequency associated with E is given by E/h. Hence the phase velocity or velocity of the individual waves constituting the group is given by

$$u = \nu\lambda = mc^2/mv = c^2/v.$$

The value of h is 6.55×10^{-7} erg/sec. For a mass of 1 g moving at 1 cm/sec. the associated wave length is 6.55×10^{-27} cm—too small to be measured at present. Wave lengths 10^{-10} to 10^{-7} cm are measurable with crystal lattices. With de Broglie's assumption we would expect corpuscular motion to exhibit phenomena like those associated with light waves under conditions where the momenta of the particles are of the order of magnitude

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$mv = h/10^{-10}$ to $h/10^{-7}$; i.e., for mv ranging from 6.55×10^{-17} to 6.55×10^{-20}. According to kinetic theory a H_2 molecule ($m = 3.7 \times 10^{-24}$) has a v of about 2×10^5 cm/sec. at room temperature. mv is then 6.6×10^{-19}, within the above-mentioned range. An electron falling through 100 volts acquires a v of 5.9×10^8 cm/sec. and $mv = 5.3 \times 10^{-19}$ and $\lambda = 1.24 \times 10^{-8}$ cm. For cathode rays of 25,000-volt velocity, λ comes out 0.75×10^{-9} cm, approximately. Several observers have found for diffracted electrons values of λ in accordance with De Broglie's relation. (Dushman, Gen. Elec. Rev., 33, 335, 1930.)

Neutrons.—Bothe and Becker (1930) bombarded various elements with Po α particles (range 3.9 cm in air, 76 cm, 0° C, initial kinetic energy 5.25×10^6 electron volts). Mg, Al, give trace of a resulting radiation, Li, Bo, Fe, notable effects, Be tremendous results—a *very* penetrating radiation. Joliot and Curie-Joliot (1931) detected it through 30 cm Pb. First considered photons but finally neutrons. Speed of neutrons from Be, 7 to 35×10^8 cm/sec. Curie and Joliot found two groups 29 and 38×10^8 cm/sec. Becker and Bothe found Be to eject 19 photons to 1 neutron. Mass of neutron $= B^{11} + He^4 - N^{14} = 1.0051 \pm 0.005$ ($O = 16$). (Darrow, Rev. Sci. Instr., 4, 58, 1933, contains bibliography.) May be considered element of atomic number 0; close combination of electron and proton. Effective collision radius 1.31×10^{-13} cm. (Rabi, Phys. Rev., 43, 828, 1933.)

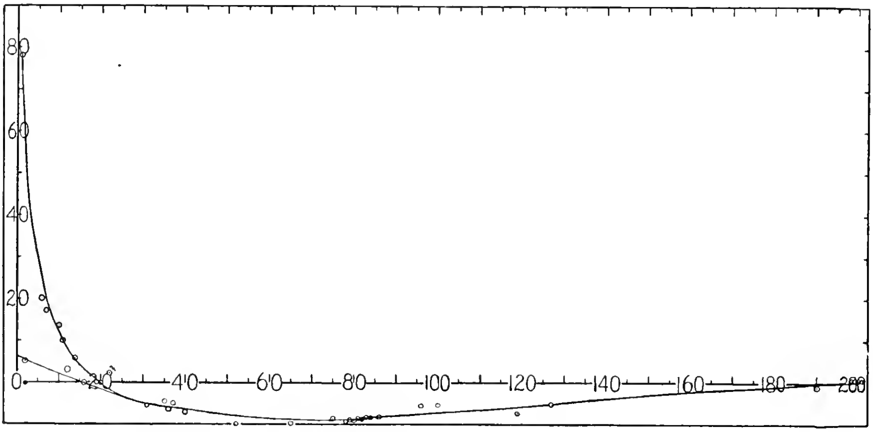
Positron.—Positive electron (Anderson, 1932) + charge $< 2e$, probably exactly equal to e and a mass comparable to a free negative electron. Probably results from the disintegration of atomic nuclei (in Anderson's case by cosmic rays). Out of total of 25,000 exposures, 1,450 cosmic ray photographs were obtained: particles of + and − charge occur in about equal numbers. Energies range $> 10^9$ volts down to few million. Mass probably less than of proton. Anderson $<$ 20 times mass of electron (Anderson, Science, 77, 494, 1933; Darrow, Rev. Sci. Instr., 4, 263, 1933, bibliography).

TABLE 851

PACKING FRACTIONS (ASTON)

(See Table 596.)

A reason for the failure of the additive law within the nucleus in atom building is because the protons and electrons become so closely packed that their electromagnetic fields interfere and a certain fraction of the mass is destroyed and appears as an electromagnetic radiation. The greater this loss, the more stable is the resulting nucleus. A convenient and informative expression for this loss is the "packing fraction," the mean gain or loss of mass per proton when the nuclear packing is changed from that of oxygen to the atom under consideration. These are given in Table 596 as parts per 10,000, and their run is indicated in the following plot (ordinates). It is a measure of the forces binding together the protons and electrons of the nucleus. The abscissae are *mass* numbers. It is to be noted that the more stable (even *atomic* numbers) lie on the lower of the two lines drawn. (See Millikan, Phys. Rev., 32, 535, 1928, for the following use of this curve.)



Aston's curve indicates that only very heavy elements can evolve energy by disintegration and there are no abundant elements above at. wt. 80 (less than 1% of all matter).

The condition necessary that even a heavy atom may liberate energy through the emission of an α particle may be seen at once from Aston's curve. Such liberation can happen only where the curve is rising so rapidly with increasing atomic weight that

$$n\Delta y > 4 \times (0.00054 - y_n).$$

n is the at. wt. of the active atom, Δy, the difference in ordinate between $(n-4)$ and n, y_n, the ordinate for the at. wt. n, and 0.00054 the value of y for He., i.e., it is the mass of the H nucleus within the α particle.

Therefore, not only very heavy atoms alone can disintegrate with the ejection of α rays and the evolution of energy, but we can compute the max. hardness, or penetrating power, of any radiations producible by radioactive disintegration.

When thorium, e.g., throws off an α particle ($n = 232$, $y_n = 0.00031$), the increase in the mass of the α particle per gram-atom, because it has escaped from the nucleus, is $4(0.00054\text{-}0.00031) = 0.00092$. The loss in mass of the residue of the Th atom $n\Delta y = 0.000034 \times 228 = 0.007752$. Therefore the total loss in mass through the emission of the α ray is $0.00775 - 0.00092 = 0.00683$ grams per gram-atom. By Einstein's equation the energy available for emission from this loss of mass is $0.00683c^2$ ergs/g-atom. The total energy from each ejection of an α particle is this divided by the Avogadro number or 1.004×10^{-5} ergs. The highest speed α ray known to be given off from Ra has an energy of 8,800,000 volts (1.2×10^{-5} ergs). ThC′ ejects in one instance an α ray with 14% more energy than this. Similarly the "upper limit" for the speed of a β ray ejected by any of the disintegration products of Th or Ra is 7,540,000 volts or again 1.2×10^{-5} ergs. Einstein's equation predicts quite within the limits of reliabilty of Aston's measurements of mass, the maximum energy available in the radioactive process.

TABLE 852.—Cosmic Rays

(Millikan, Cameron, Phys. Rev., 31, 921, 1928; 32, 533, 1928.)

The measurements on the absorption coefficients for the cosmic rays indicate a complex set of entering rays which may be analyzed into separate rays with mean absorption coefficients (μ) per meter of water of 0.02, 0.04, 0.08, and 0.30.

Formation of He nucleus from hydrogen: From Einstein's equation and Aston's curve (Table 851) the loss of mass in the formation in a single act of the nucleus of He from four + electrons and two − electrons is $4 \times 1.00778 - 4 \times 1.00054 = 0.029$ g/g-atom, and the radiant energy released each time this act occurs is

$$(0.029 \times 9 \times 10^{20})/(6.062 \times 10^{23}) = 4.3 \times 10^{-5} \text{ ergs.}$$

$\nu = (4.3 \times 10^{-5})/(6.547 \times 10^{-27}) = 6.57 \times 10^{-21}$, $\lambda = 0.00046$ A. From Dirac's relativity-quantum-mechanics formula $\mu = 0.30$ per meter H_2O.

Oxygen from hydrogen: $16 \times 0.00778 = 0.1245$ g/g-atom $\mu = 0.074$ per m H_2O.
Nitrogen " " 0.108 g/g-atom $= 0.086$.
Mean of these two corresponds to 0.08.
Silicon gives $\mu = 0.041$. Iron " $\mu = 0.019$.

So that the observed μ of the cosmic ray may correspond to the creation from hydrogen of He ($\mu = 30$), O (.08), Si (.04) and Fe (.02).

Cosmic rays (A. H. Compton, Phys. Rev., 43, 387, 1933).—Intensity vs. altitude curves indicate not only a rapid increase in ionization intensity with altitude but also that at each alt. the intensity is greater for high lat. than near the Equator. At sea-level the intens. at high lat. is 14% greater than at Equator; at 2000 m alt., 22%, at 4360 m, 33% greater. With arbitrary constants corresponding to 1.605 ions due to rays unaffected by the earth's magnetic field (neutral rays or electrons of energies $> 4 \times 10^{10}$ electron-volts), and a band of electrons approaching the earth with energies between 0.5×10^{10} and 1.3×10^{10} electron-volts reaching the earth at lat. $> 50°$ and producing 0.235 ion, but failing to reach the earth at the Equator, Compton's observations will bear out the theory of Lemaitre and Vallarta (Phys. Rev., 42, 914, 1932). The extra component appearing at high lat. is more rapidly absorbed than the main body of rays. This would be anticipated if rays unaffected by earth's magnetic field were of electrons of greater energy; or a uniform background due to neutral rays such as photons, neutrons, or high speed neutral atoms. Average intensity lat. 0° to 22°, sea-level, 1.620 ± 0.006 ions per cm per sec.; lat. $> 48°$, 1.839 ± 0.006 ions.

Cosmic rays (Millikan, État actuel de nos connaissances sur le lieu et la mode de production des Rayons Cosmiques, Congrès international d'Electricité, 1932; Phys. Rev., 43, 661, 1933; 43, 695, 1933; Science, 77, 494, 1933; 77, May 5, 1933).—Most distinctive results: (A) Ionization-altitude curve (to 18 km or 92% through the atmosphere) does not rise exponentially clear to top with apparent absorption coefficient about 0.6 per m H_2O (all observers get this, say 5 to 9 km) but shows a marked decrease 9 km to top (about 12 km), actually becoming concave downward. This is inconsistent with (1) incoming rays primarily of charged particles, (2) photons in complete equilibrium with their secondaries, (3) rays of the penetrating power of γ rays or rays between these and the least energetic cosmic rays. They show non-ionizing primary entering rays not yet in equilibrium with secondaries.

The rays show a rapid softening with altitude (essentially the same in temperate and equatorial latitudes); best interpreted by cosmic photon bands of widely differing penetrating powers as from the production of He, O, Si, Fe, etc. More than $\frac{3}{4}$ of the cosmic rays at 7.6 km have energy $< 350{,}000{,}000$ volts. Millikan considers that the "cosmic rays" found at low altitudes are secondaries formed in the earth's atmosphere by collisions of photons with air atoms. Anderson has caught the cosmic rays, which cannot themselves be photographed, in the act of smashing atoms, setting loose + and − charged particles. So all but a small fraction of the cosmic rays at sea-level are secondaries produced in the earth's atmosphere.

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(See Nat. Res. Council Bull. 85, 1932.)

TABLE 853.—Area of Ocean Depths (Littlehales)

Area of total water surface is about 365,500,000 km². (Land surface about 153,500,000 km².)

Meters	0-200	200-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000	>6000
$km^2 \times 10^6$	30.60	16.40	18.05	36.45	79.01	112.72	66.88	5.38
%	8.4	4.4	4.9	9.9	21.7	30.8	18.4	1.5

The continental shelf dips gradually (depth contour about 200 m); then a steeper continental slope (talus), the seat of many deposit slips, seismic disturbances. Insular shelves and taluses, then troughs, trenches, basin deeps.

TABLE 854.—Oceanic Gradients

Ocean bottom gradients, Atlantic Ocean between Equator and 47° N. latitude.

Zone, N. lat.	0–10°	10–20°	20–25°	25–30°	30–35°	35–40°	40–47°
Gradient	20′.7	28′.7	28′.7	23′.9	24′.1	36′.2	37′.1

Island gradients often great; St. Helena, up to 40°; St. Paul (Atlantic Ocean), 62°. Gradients for volcanic and coral islands also great, generally in upper 300 m. Great Caldera of Santorin > 50°. S. of Cuba, 76° W., to depth 2625 m, 35° 30′. Compare Fujiyama, Japan, fine volcanic peak, 35°; 12° at base. Steep gradients (Alpine conditions) westward of British, French, Iberian coasts (av. angle 13° to 14°) and W. of continental slope of California (San Diego to Point Conception) 14° between 2000 and 4000 m isobaths.

TABLE 855.—Atlantic Ocean Basin. Areas and Depths (Littlehales)

Depths, km	0-2	2-4	4-6	6-8	Over 8	Total area
Areas, 10^6 km²	29.49	19.50	50.60	7.38	0.039	107.014900
% of whole	27.6	18.2	47.3	6.9	0.4	100

Remarkable feature: Mid-Atlantic Rise, of median course and continental extent, from Iceland to S. polar border; throughout its more than 13 km, the general rise of its crest is some 3 km above the basin bottom on each side. W. Atlantic trough 6 km deep over large area of N. portion; other troughs and basins of similar depth. European isolated depth of 6 km. Near Equator lessened depth, 1.9 km, and extension along Equator 34° to 15° W. long., cut by narrow gap 18° W., 4 to 5 km deep. Passage through gap leads to Brazilian basin, 7.4 km deep. Ridge < 1 km deep leads from Greenland (Iceland is a volcanic rise) to British Isles.

Greatest depths: 54° 30′ S., 28° 30′ W., 8.050 km; 19° 36′ N., 66° 26′ W., 8.351 km; 19° 35′ N., 67° 43′ W., 8.525 km; 19° 38′ N., 68° 17′ W., 8.198 km. See also page 651. Greatest depth in Mediterranean, 4.400 km at 35° 45′ N., 21° 46′ E.; Black Sea, entire central basin below 2 km; North Sea < 200 m throughout.

TABLE 856.—Indian Ocean Basin. Areas and Depths (Littlehales)

Depths, km	0-2	2-4	4-6	Over 6	Total area
Areas, 10^6 km²	8.192	18.569	44.569	4.656	75.986000
% of whole	10.8	24.4	58.7	6.1	100

Compared with Atlantic the bottom relief of the Indian Ocean is much simpler. 7 km deep 250 km S. of Java 10° 1′ S., 108° 65′ E. Persian Gulf, order of 0.09 km deep. Red Sea, about 2 km.

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(See Nat. Res. Council Bull., 85, 1932.)

TABLE 857.—Pacific Ocean Basin. Areas and Depths (Littlehales)

Depths, km	0-2	2-4	4-6	6-8	Over 8	Total area
Areas, 10^6 km^2	18.580	31.632	115.593	11.426	0.521	177.752
% of whole	10.5	17.8	65.0	6.4	0.3	100

With much more steeply sloping shores on the E. and W., this ocean, with its Polynesian characteristics, presents a very irregular depth map. Along W. coasts of both N. and S. America steep slopes are remarkable, descending from great heights of Rocky Mts. and the Andes to depths of 4 km or more within short distances; off S. A., between 10° and 35° S., depths to 8 km near coast. All soundings > 8 km near land, off S. A., Aleutian Is., Kurtle Is., Japan, etc. There are numerous isolated volcanic formations, *e. g.*, Hawaiian chain. The largest and deepest depressions are in the gigantic Pacific basin. Tuscarora deep, 8.513 km; 3 elongated tracts 45°, 38°, 31° lat. > 8 km for 38 km^2. Manchu deep, 31° N., 142° E., 9.435 km for 4 km^2; Fleming deep, 23° 48′ N., 144° 6′ E., 8.650 km deep; Tonga deep, 23° 39′ N., 175° 4′ E., 9.184 km; Aleutian deep > 6 or 7 km near S. A., 25° 42′ S., 71° 31′ W., 7.635 km. These deeps are as a rule not associated with the pits of great basins but are nearer land.

Note: The Arctic basin is about $\frac{1}{6}$ of Atlantic Ocean in extent; greatest depths about 4 km. The Antarctic Ocean basin falls steeply from its continent to 2 km.

TABLE 858.—Physical Properties of Sea Water (Thompson)

Temperatures.—Tropical, surface up to 28° C, < 0° C at bottom. Northern Pacific, extreme variation < 6° throughout. Generally decreases with depth.

Pressure.—Atmospheric surface pressure generally neglected, called zero. Pressure is f(wt.) = f(temperature, chlorinity, compressibility, latitude). Gravity = f(latitude). Bjerknes (1909) proposed a "bar" as unit of pressure = that due to column of water 10 m high.

Concentration.—Dilute solution of several strong electrolytes. An ionizing medium better than distilled water; dielectric constant is greater. Composition much the same, varying mainly in dilution.

Salinity (s) is defined as the total amount of solid material in one kg of sea water when all the carbonates have been converted into oxides, the Br and I replaced by Cl and all organic matter completely oxidized. **Chlorinity** (Cl) = total amount chlorine in one kg when all the Br and I have been replaced by Cl. S = 0.03 + 1.805 Cl. Thus chlorinity may be reduced to salinity (Knudsen, Hydrographical Tables, Copenhagen, 1901). The principal ions, chlorinity 19.374% are (Ditmar, 1884):

Cations	Na^+	Mg^{++}	Ca^{++}	K^+	Anions	Ce^-	SO_4^{--}	HCO_3^-	CO_3^-	Br^-
g/kilo	10.722	1.207	0.417	0.382	g/kilo	19.337	2.705	0.097	0.007	0.066
moles/l	.4662	.0533	.0104	.0098	moles/l	.5453	.0281	.0016	.0001	.0008
Totals:			12.818	g/kilo	Totals:			22.212	g/kilo	
			0.5397	moles/l				0.5759	moles/l	

For fresh water Ca^+, HCO_3^-, and CO_3^- predominate.

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(See Nat. Res. Council Bull., 85, 1932.)

TABLE 858 (*continued*).—Physical Properties of Sea Water (Thompson)

Adiabatic cooling for sea water, chlorinity 19.29%, 2° C, when brought from various depths to the surface (Ekman, Schott, Amer. Hydrogr. 321, 1914):

Depth, meters	1000	2000	4000	6000	8000	10000
Cooling, °C	0.06	.14	.36	.63	.96	1.33

Color and transparency.—(See Atkins, Journ. Conseil, 1, 99, 1926.) Optically pure water becomes bluer with depth. Green tints due to suspended matter. A rough measure may be taken as the depth where a white immersed disk becomes just invisible; coastal water, 5 to 25 m, often 45 to 60 m. Max. record 66 m (Sargasso Sea).

Density taken as S_0, sp. gr. at 0° referred to distilled water at 4°. Density expressed as $\sigma_0 = (S_0 - 1)1000$. $\sigma_0 = -0.069 + 1.4708\ Cl - 0.00157\ Cl^2 + 0.0000398\ Cl^3$.

Chlorinity	5%	10%	15%	20%	
Density 0° C	5.45	10.90	20.35	25.81	
" 20° C	5.00	10.40	15.75	25.15	
Max. density °C	2.1	+0.1	−1.9	−3.8	
Freezes °C	0.5	−1.0	−1.5	−2.0	
Conductivity 0° C	.0085	.0160	.0235	.0305	Reciprocal ohms
" 20° C	.0140	.0265	.0385	.0500	
Refractive index 0° C	1.3358	1.3376	1.3394	1.3412	
" " 20° C	1.3347	1.3364	1.3381	1.3397	
Sp. heat 17°.5 C	.9971	.9954	.9942	.9930	Atm. pressure
Conductivity 17°.5 C	1370.	1356.	1348.	1341.	Thermal, all × 10^8
Surface tension 0° C	77.3	77.5	77.7	77.85	Dynes/cm
" " 20° C	73.7	73.9	74.1	74.3	" "
Sp. viscosity 0° C	1.015	1.030	1.045	1.060	Referred to distilled H_2O, 1.00 at 0° C
" " 10° C	.74	.755	.765	.78	
" " 20° C	.57	.58	.59	.605	

Velocity of sound: Chlorinity, 19.37%; salinity, 35.00%

Depth, meters	0	0	2000	4000	6000	8000
Velocity m/sec.	[1630]20° C	[1560	1590	1625	1660	1695]0° C

TABLE 859.—Chemical Composition of Sea Water (Thompson, Robinson)

Concentration as millimols or milligram atoms per kilogram

Cl	535.0	CO_2	2.25	B	0.037	Cu	0.002	Zn	0.00003
Na	454.0	Br	.81	Li	.015	Ba	.0015	H ion	.00001
Sulphate	82.88	Sr	.15	Nitrate	.014	I	.00035	Au	.00000025
Mg	52.29	Al	.07?	Fe	.0036	Ag	.0002		
Ca	10.19	F	.043	Mn	.003?	Nitrite	.0001		
K	9.6	Si	.04	P	.002	As	.00004		

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(See Nat. Res. Council Bull. 85, 1932)

TABLE 860.—Waves of the Sea (Patton, Marmer)

Wave forms.—Progression of wave form across a stretch of water; actual cyclic movement (circular in deep water; elliptical, long axis horizontal, in shallow) of particle; there also may be a forward propagation of particles. Form of ocean wave, trochoid or prolate cycloid. If $a =$ height of crest, $b =$ depth of trough, both from undisturbed water level, h and l, the height and length of wave, then $a = (h/l) + 0.7854(h^2/l)$; $b = (h/2) - 0.7854(h^2/l)$ (Gaillard, 1904).

Wind waves in deep water are surface waves. Particle motions decrease rapidly with depth; halved for each $1/9\, l$ of depth. If height of wave = vertical distance between crest and trough, l, distance between consecutive same phases, v, velocity, p, period, $v = l/p$; $v = (g/2\pi)^{\frac{1}{2}} l$; $g =$ gravity; $p = (2\pi/g)^{\frac{1}{2}} l = (2\pi/g) v$; $l = (g/2\pi) p^2 = (2\pi/g) v^2$.

Principal factors: Strength and duration of wind, fetch exposed to wind. Highest (hurricane) waves in open sea, about 15 m; may be higher through interference, etc., over 30 m. No fixed relation between l and h. Some observed ratios (Gaillard): h, 0.6 to 1.5 m, 30; 3 to 6 m, 20; $>$ 9 m, 14. 150 m long not uncommon; some up to 300 m.

Swell.—As waves pass from disturbed area they degenerate to a gentle swell; not important in mid-ocean but may be dangerous to exposed coasts and harbors. Periods (Morocco coasts) 7 to 20 sec., height 0.45 to 4.5 m.

Waves in shallow water are considerably different. If depth of water greater than length of wave, water deep; less, shallow. Wave of translation (Russell, Rep. British Assoc., 8, 417, 1838; 14, 311, 1845).—All the water is above the undisturbed level; there is actual translation of the water particles; due to sudden addition of water, as with breaking of a wave.

Wave pressure may be as great as 3.3×10^6 dyne/cm^2.

Seismic waves: Lisbon tidal wave, 1755, 18.3 m; Krakatoa, 1883, 21 m at Telok Betong.

Tables 861-863

TABLE 861.—Properties of Carboloy

(Hoyt, Hard metal carbides and cemented tungsten carbides, Trans. Amer. Inst. Metals, Inst. of Metals Division, p. 9, 1930.)

Carboloy is a cemented tungsten carbide, WC + 13% Co. At. vol. of the C atoms indicates that they assume the structure of the diamond. Especially adapted to high-speed cutting tools—long life, great hardness and strength.

Per cent cobalt	3	6	9	13	20	100
Density, g/cm^3	15.04	14.82	14.56	14.10	12.54	8.62
Rockwell A hardness, C scale, 60 kg.		90		87		
Vicker Brinell number *	1380a	1450a	1365a	1255b	755b	280b
Elec. resistance, michroms/cm^3, 20° C.	21.3	21.1	22.3	19.6	29.2	9.84
Ditto, temp coef., 20-30° C	.0047	.0045	.0043	.0044	.0038	.0036

* (a) 10 kg load. (b) 30 kg load.

Carboloy:

Modulus of rupture, cross bending, 20° C, about 225000; 800° C, 183000; 850°, 170000; 900°, 141000 lb./in^2.

Expansion coefficient per °C, 20 to 400° C, .000006

Thermal conductivity, watts/cm/°C, .65.

Specific heat, cal./g, .052.

Wiedermann-Franz constant (watts/ohm/°C) $\times$ 10^6, 20° C, 12.2.

Hardness at high temp. Brinell, 1100° C, 36; 1300° C, 2.7.

Magnetizing force, gilberts/cm	100	200	300	500	700	900	1000
Induction, kilogauss	0.58	1.10	1.50	2.17	2.67	3.10	3.29

TABLE 862.—Properties of Dekhotinsky Cement

Dekhotinsky cement for air-tight joints. Sp. resistance 2×10^{15} ohm · cm and inductive capacity higher than of mica; adhesion great. For cementing glass and metals. Nitric, sulphuric, hydrochloric acids, bisulphide of carbon, benzene, gasoline, turpentine do not attack it. Very little affected by ether, chloroform, caustic alkalies, etc.

TABLE 863.—Properties of Fused Quartz (Vitreous Silica)

Fused quartz (vitreous silica). Can be used to a working temperature of 1000° C. Softens about 1400°, melts about 1756° C. Can be used intermittently to 1700° but above 1000° devitrification commences.

Thermal expansion low, .0000005 per ° C up to 1000°.
Invar, .0000009.
Chemical pyrex, .0000032.
Jena glass 59, .0000057.

Expands on continued cooling to 80° C.

Specific gravity: clear fused, 2.21, translucent, 2.1.

Hardness, Moh's scale, fused, 4.9, crystal, 6.3.

Modulus of elasticity, 9,400,000 lbs./in.^{2}

Tensile strength, 7,000 lbs./in.^{2}

Compression strength, 190,000 lbs./in.^{2}

Impermeability. Not porous to common gases at high T and ordinary pressures.

Helium diffuses through even at low T. Non-hygroscopic.

Transparent to radiation about .1850 to 1μ.

Thermal conductivity at 20° C .0024 for clear fused quartz, increases rapidly with rise in temperature.

Resistivity electrical, 5×10^{18} ohm · cm 25° C.

Dielectric constant, 100000 cycles, 25° C, 60% humidity = 4.4.

Most acids, neutral salts, refractory oxides, either no chemical action or less than with glass, Pt, or porcelain. Hot solutions and fusions of the caustic alkalies readily attack.

(Vitreous silica, Sosman, 1927; Fused quartz, Gen. Elec. Co., 1928.)

TABLE 864.—Properties of Phenol-Resinoid Products

Quality	Pure hardened resinoid	Molded			Laminated	
		Wood floor filler	Fabric filler	Asbestos filler	Paper	Fabric
Molding qualities	none	excellent	good	fair	sheets, tubes, rods, etc.	
After molding	.....	permanently infusible			permanently infusible	
Machining	good	fair	fair	fair	fair	fair
Cold flow	none	none	none	none	none	none
Transparency	transparent translucent	opaque			opaque	
Refractive index	1.56–1.70	opaque			opaque	
Specific gravity	1.2–1.3	1.3–1.4	1.3–1.4	1.8–2.0	1.3–1.4	1.3–1.4
Tensile strength lb./in.² Fig. 8 test piece	5,000 to 11,000	6,000 to 12,000	6,000 to 12,000	3,500 to 5,000	8,000 to 20,000	8,000 to 12,000
Elongation	negligible	negligible			negligible	
Modulus of elasticity transverse lbs./in.²	10–25 $\times 10^5$	.....	.....	.....	.....	.....
Modulus of rupture transverse lbs./in.²	12,000 to 20,000	10,000 to 20,000	8,000 to 15,000	8,000 to 20,000	flat or edge-wise 75,000 to 30,000	to 25,000
Electrical resist. $\omega \cdot cm^3$	10^{10} to 10^{12}	10^{10} to 10^{11}	10^{10} to 10^{11}	10^8 to 10^9	10^{10} to 10^{11}	10^9 to 10^{10}
Breakdown volts,* V/mil	250–700	300–500	20–500	150–400†	500–1300	200–500
Power factor 10^6 cycles	4.5 to 7	4.5 to 8	4.5 to 7	5 to 20	4.5 to 6	4.5 to 7
Thermal conductivity cal./sec. cm° C	3–4 $\times 10^{-4}$	4–6 $\times 10^{-4}$	4–6 $\times 10^{-4}$	12–20 $\times 10^{-4}$	5–8 $\times 10^{-4}$	5–8 $\times 10^{-4}$
Sp. heat	.33–.36	.....	.30–.40	.....	.30–.40	
Burning	extremely low		nonflamable		extremely low	

Instantaneous at 60 cycles. † Mica filler.

.nimal, vegetable, mineral oils, hydrocarbons, esters, ketones, no effect; alcohols, practically none; k alkalies, slowly softened, strong, disintegrates; decomposed by strong nitric and sulphuric acids by hydrochloric and hydrofluoric which attack fillers. Withstands 250° F. (Data from Mory and lor, Bakelite Corporation, 1920.)

TABLE 865.—High Vacuum Technique

.eferences: Dunoyer, Vacuum practice, London, Bell and Sons, 1926; Newman, The production measurement of low pressures, New York, Van Nostrand, 1925; Kaye, High vacuum, Longmans, en & Co., 1927; Dushman, High vacuum, Gen. Elec. Rev., 1922; Goetz, Physik und Technik der hvakuums, Vierveg und Sohn, Akt. Ges., Braunschweig, 1926; Langmuir, Phys. Rev., 2, 450, 1930; s. Zeitschr., 15, 516, 1914.

he following is taken from Dushman, Rev. Mod. Phys., 2, 381, 1930, whence the above references. stop-cocks, greased joints, etc., should be avoided in connection with the exhaust and preparation ıbes containing cathodes for which electron emissivity are to be determined. While the evaporation / with the bulb immersed in liquid air was used by Langmuir, other "getters" have come into use. Ca, Ba, and alloys of rare-earth metals have been used. Ba cleans up practically all residual gases rdinary temperatures, while Mg is ineffective for H_2 and Ca does not take up N to any great extent. emely low pressures may be obtained with a side tube containing charcoal (which has been well ısted) immersed in liquid air. Care should be taken that the liquid air is maintained at constant during the series of measurements.

TABLE 866.—Relative Viscosity of Water; High Pressure Variation

(Bridgman, 1925.)

kg/cm²	1	500	1000	2000	4000	6000	8000	10000	11000
0° C.	1.000	0.938	0.921	0.957	1.111	1.347			
10.3°	.779	.755	.743	.754	.842	.981	1.152		
30°	.488	.500	.514	.550	.658	.786	.923	1.058	1.126
70°	.222	.222	.239	.258	.302	.367	.445		

TABLE 867.—Viscosity of Mercury; High Pressure Variation

(Bridgman, 1927.)

Pressure kg/cm²	1	2000	4000	6000	8000	10000	12000
Abs. visc. 30°	0.01516	0.01588	0.01663	0.01742	0.01825	0.01913	0.02008
" 75°	.01341	.01399	.01463	.01528	.01599	.01675	.01757
% increase 30°	.0	5.1	9.9	15.2	20.0	26.3	33.5
75°	.0	4.6	9.6	14.4	18.8	24.7	31.1

TABLE 868.—Viscosity of Some Glasses at High Temperatures

(Washburn, Shelton, Libmann, Bull. Univ. Illinois, 140, 1924.)

Composition			Surface tension dynes/cm²		Viscosities					
SiO_2	Na_2O	CaO	1206°	1454°	800°C	900°	1000°	1200°	1400°	1500°
49.7	50.3	....	...	...	....	2.32	1.62	0.93	....	....
60.0	40.0	....	156	149	4.51	3.68	3.04	2.05	1.26	0.91
70.0	30.0	....	164	154	5.14	4.30	3.64	2.62	1.89	1.58
82.6	17.4	....	...	154	....	....	5.4	3.69	2.64	2.33
54.25	38.0	7.75	115	154	....	(6.05)	3.42	1.64	.88	....
60.0	30.0	10.0	...	...	....	(3.5)	3.02	2.18	1.44	1.08
60.0	20.0	19.5	160	128	....	....	4.95	2.14	1.32	.93
63.0	13.6	23.4	164	159	....	....	5.16	2.63	1.51	1.19
64.95	19.3	15.75	150	139	....	4.92	3.88	2.58	1.75	1.41
67.5	15.5	17.0	159	145	....	5.50	4.37	2.89	1.91	1.57
68.1	21.9	10.0	150	146	5.18	4.44	3.76	2.59	1.80	1.44
70.0	20.0	10.0	154	140	5.63	4.68	3.93	2.78	1.94	1.58
70.0	10.0	20.0	164	156	....	....	....	3.84	2.16	1.77
72.25	15.1	12.1	...	152	....	5.46	4.36	3.03	2.09	1.64
73.5	16.5	10.0	167	159	5.73	5.09	4.46	3.26	2.18	1.68
73.0	12.0	15.0	...	...	....	....	....	3.71	2.80	2.43

TABLE 869.—Some Possible Accuracies, 1928

(Journ. Wash. Acad. Sci., 18, 503, 1928.)

Pienkowsky:

30 national prototype kgm (and probably the international kilogram) are remaining constant within 0.02 mg or less.

10^{-6} kg measurable to 1 part in 10^4.

1 " " " " " " 10^9.

10^3 " " " " " " 10^6.

With one type of microbalance 100 mg to 1 mg, 1 part in 10^8 to 10^6.

Curtis:

1 ohm, 1 to 2 parts in 10^7; 1 millimicrohm with 10%, also megamegohm.

1 volt, 1 in 10^7; 1 microvolt, 1%; 1 megavolt, 10%.

1 ampere, 1 in 10^6; micromicroampere 10%; kiloampere 1 in 10^4.

1 millihenry, 1 in 10^5; millimicrohenry, 10%; kilohenry 1%.

1 microfarad, 1 in 10^5; micromicrofarad, 1%; millifarad 1%.

PROPERTIES OF MALLEABLE CAST IRON

(From Proc. Amer. Soc. for Testing Materials, 31, pt. 2, 1931; Malleable Iron Research Institute.)

Malleable iron is the product produced by the annealing or graphitization of " white iron " castings in which all carbon should be present in the combined form, such that the final structure of the malleable casting consists of ferrite and free carbon (temper carbon) with practically no combined carbon as free cementite or pearlite. Where strength, ductility, machineability, and resistance to shock are important, malleable iron castings are of wide application.

Chemical composition: C 1.00 to 2.00; Si 0.60 to 1.10; Mn $< .30$; P $< .2$; S .06 to .15%.

Density: 7.15 to 7.45. Thermal expansion: 20°-400° C, about 0.000012 per °C.

Sp. Ht.: Mean 20°-100° C, 0.122 per g per °C; 20°-200°, 0.125; 20°-500°, 0.139; 20°-700°, 0.159.

Thermal conductivity: Kt, 50° C, 0.145 g. cal./sec./°C/cm; 100° C, 0.137; 200° C, 0.115.

Tensile strength: 54,000 lbs./in.^{2}; range 45,000 to 63,000; yield point 36,000 lb./in.^{2}

Elongation in 2 in. 18%. Modulus of elasticity in tension 25,000,000 lb./in.^{2}

Compressive strength: Material flows indefinitely.

" Special " tensile 57,690; yield point 38,000; elongation 25% in 2 in.

Ultimate shearing strength 48,000 lb./in.^{2}; yield point 23,000 lb./in.^{2}; elasticity mod. 12,500,000 lb./in.^{2}

Modulus rupture in torsion 58,000 lb./in.^{2}; yield point in torsion 24,000 lb./in.^{2}

Brinell hardness 115, range 100 to 140. Charpy impact value 7.75 ft. lb.

Note: If malleable iron is heated above its lower critical point (about 760° C), carbon redissolves and the character of the iron changes.

Resistivity: 28 to 37 microhms · cm^3 $R_{100}/R_0 = 1.1$ $R_{300}/R_0 = 2.3$.

Magnetizing force, H, gilberts/cm......	2.5	5	7.5	10	15	20	30
Induction, B, gausses (mean)...........	5800	7600	9200	10000	11000	11400	11900

Comparative machineability. Relative power required (means of planing, drilling, and milling):

Dow metal, type E....	19	Gun metal	55	Copper annealed	131
Bearing bronze	36	Cast iron	60	Tool steel 1.03% C...	145
Aluminum alloy no. 31.	37	Manganese bronze ...	61	Stainless Cr, iron, ann.	158
Red brass	38	Malleable cast iron..	70	Monel metal	165
Sheet brass	41	Unleaded brass	85	Nickel "A"	193

DEFINITIONS OF UNITS

ACTIVITY. Power or rate of doing work; unit, the watt.

AMPERE. Unit of electrical current. The international ampere, "which is one-tenth of the unit of current of the c.g.s. system of electromagnetic units, and which is represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water, and in accordance with accompanying specifications, deposits silver at the rate of 0.00111800 of a gram per second."

The ampere = 1 coulomb per second = 1 volt through 1 ohm = 10^{-1} e.m.u. = 3×10^{9} e.s.u.

Amperes = volts/ohms = watts/volts = (watts/ohms)$^{\frac{1}{2}}$.

Amperes × volts = amperes^2 × ohms = watts.

ANGSTROM. Unit of wave length = 10^{-10} meter.

ASTRONOMICAL UNIT. Mean distance earth to sun, 149,500,000 km.

ATMOSPHERE. Unit of pressure.

English normal = 14.7 pounds per sq. in. = 29.929 in. = 760.18 mm Hg. 32° F.

French " = 760 mm of Hg. 0° C = 29.922 in. = 14.70 lbs. per sq. in.

AVOGADRO NUMBER. Number of molecules per mole 6.064×10^{23} mole^{-1}.

BAR. International unit of pressure 10^6 dyne/cm^2, g = 980.616 cm/sec^2.

BARYE. c.g.s. pressure unit, one dyne/cm^2.

BRITISH THERMAL UNIT. Heat required to raise one pound of water at its temperature of maximum density, 1° F. = 252 gram-calories.

CALORIE. Small calorie = gram-calorie = therm = quantity of heat required to raise one gram of water at its maximum density, one degree Centigrade.

Large calorie = kilogram-calorie = 1000 small calories = one kilogram of water raised one degree Centigrade at the temperature of maximum density.

For conversion factors *see* page 251.

CANDLE, INTERNATIONAL. The international unit of candlepower maintained jointly by national laboratories of England, France and United States of America.

CARAT. The diamond carat standard in U. S. = 200 milligrams. Old standard = 205.3 milligrams = 3.168 grains.

The gold carat: pure gold is 24 carats; a carat is 1/24 part.

CIRCULAR AREA. The square of the diameter = 1.2733 × true area.

True area = 0.785398 × circular area.

CIRCULAR INCH. Area of circle one inch in diameter.

COULOMB. Unit of quantity. The international coulomb is the quantity of electricity transferred by a current of one international ampere in one second = 10^{-1} e.m.u. = 3×10^{9} e.s.u.

Coulombs = (volts-seconds)/ohms = amperes × seconds.

CUBIT = 18 inches.

DALTON. Unit of mass, 1/16 mass of oxygen atom. 1.65×10^{-24} g.

DAY. Mean solar day = 1440 minutes = 86400 seconds = 1.0027379 sidereal day.

Sidereal day = 86164.10 mean solar seconds.

DIGIT. $\frac{3}{4}$ inch; 1/12 the apparent diameter of the sun or moon.

DIOPTER. Unit of "power" of a lens. The number of diopters = the reciprocal of the focal length in meters.

DYNE. c.g.s. unit of force = that force which acting for one second on one gram produces a velocity of one cm per sec. = 1g ÷ gravity acceleration in cm/sec./sec.

Dynes = wt. in g × acceleration of gravity in cm/sec./sec.

ELECTROCHEMICAL EQUIVALENT is the ratio of the mass in grams deposited in an electrolytic cell by an electrical current to the quantity of electricity.

DEFINITIONS OF UNITS

FOOT-POUND. The work which will raise one pound one foot high.
For conversion factors *see* page 251.
FOOT-POUNDALS. The English unit of work = foot-pounds/g.
For conversion factors *see* page 251.
EQUATION OF TIME. Excess of mean time over true time.
ERG. c.g.s. unit of work and energy = one dyne acting through one centimeter.
For conversion factors *see* page 251.
FLUIDITY. Reciprocal of viscosity.
g. The acceleration produced by gravity.
GAUSS. A unit of intensity of magnetic field = 1 e.m.u. = $\frac{1}{3} \times 10^{-10}$ e.s.u
GRAM. *See* page 6.
GRAM-CENTIMETER. The gravitation unit of work = g. ergs.
GRAM-MOLECULE = x grams where x = molecular weight of substance.
GRAVITATION CONSTANT = G in formula $G\frac{m_1m_2}{r^2} = 666.4 \times 10^{-10}$ dyne · cm² · g⁻².
HEAT OF THE ELECTRIC CURRENT generated in a metallic circuit without self-induction is proportional to the quantity of electricity which has passed in coulombs multiplied by the fall of potential in volts, or is equal to (coulombs × volts)/4.181 in small calories.
The heat in small or gram-calories per second = (amperes^2 × ohms)/4.181 = volts^2/(ohms × 4.181) = (volts × amperes)/4.181 = watts/4.181.
HEAT. Absolute zero of heat = − 273°.18 C.
HEFNER UNIT. Photometric standard; *see* page 334.
HENRY. Unit of induction. It is "the induction in a circuit when the electromotive force induced in this circuit is one international volt, while the inducing current varies at the rate of one ampere per second" = 10^9 e.m.u. = $1/9 \times 10^{-11}$ e.s.u.
HORSEPOWER. The English and American horsepower is defined by some authorities as 550 foot-pounds per second and by others as 746 watts. The continental horsepower is defined by some authorities as 75 kilogrammeters per second and by others as 736 watts. *See* page 251.
JOULE. Unit of work = 10^7 ergs. For electrical Joule see page xlv.
Joules = (volts^2 × seconds)/ohms = watts × seconds = amperes^2 × ohms × sec.
For conversion factors *see* page 251.
JOULE'S EQUIVALENT. The mechanical equivalent of heat. *See* page 86.
KILODYNE. 1000 dynes. About 1 gram.
KINETIC ENERGY in ergs = grams × (cm/sec.)^2/2.
LITER. *See* page 6.
LOSCHMIDT NUMBER. Number of molecules per unit vol. ideal gas at 0° C and normal pressure, 2.705×10^{19} cm^{-3}.
LUMEN. Unit of flux of light-candles divided by solid angles.
MEGABAR. Unit of pressure = 1,000,000 bars = 0.987 atmospheres.
MEGADYNE. One million dynes. About one kilogram.
METER. *See* page 6.
METER CANDLE. The intensity of lumination due to standard candle distant one meter.
MHO. The unit of electrical conductivity. It is the reciprocal of the ohm.
MICRO. A prefix indicating the millionth part.
MICROFARAD. One-millionth of a farad, the ordinary measure of electrostatic capacity.
MICRON. (μ) = one-millionth of a meter.
MIL. One-thousandth of an inch.
MILE. *See* pages 5, 6.
MILE, NAUTICAL or GEOGRAPHICAL = 6080.204 feet.
MILLI-. A prefix denoting the thousandth part.
MOLE. Mass equal to molecular weight of substance.

DEFINITIONS OF UNITS

MONTH. The anomalistic month = time of revolution of the moon from one perigee to another = 27.55460 days.

The nodical month = draconitic month = time of revolution from a node to the same node again = 27.21222 days.

The sidereal month = the time of revolution referred to the stars = 27.32166 days (mean value), but varies by about three hours on account of the eccentricity of the orbit and "perturbations."

The synodic month = the revolution from one new moon to another = 29.5306 days (mean value) = the ordinary month. It varies by about 13 hours.

OHM. Unit of electrical resistance. The international ohm is based upon the ohm equal to 10^9 units of resistance of the c.g.s. system of electromagnetic units, and "is represented by the resistance offered to an unvarying electric current by a column of mercury, at the temperature of melting ice, 14.4521 grams in mass, of a constant cross section and of the length of 106.3 centimeters" = 10^9 e.m.u. = $1/9 \times 10^{-11}$ e.s.u.

International ohm = 1.01367 B. A. ohms = 1.06292 Siemens' ohms.

B. A. ohm = 0.98651 international ohms.

Siemens' ohm = 0.94080 international ohms.

PARSEC. Distance of star whose parallax is 1″.

PENTANE CANDLE. Photometric standard. *See* page 334.

PI = π = ratio of the circumference of a circle to the diameter = 3.14159265359.

POUNDAL. The British unit of force. The force which will in one second impart a velocity of one foot per second to a mass of one pound.

RADIAN = $180°/\pi = 57.29578° = 57°\ 17'\ 45'' = 206265''$.

REAMUR. Thermometric scale. 0° C = 0° R. 100° C = 80° R.

SECOHM. A unit of self-induction = 1 second × 1 ohm.

SLUG. Unit of mass. Mass acquiring acceleration 1 ft./sec.^{2} when continuously acted upon by 1 lb. wt.

SLUG. (Metric) ditto accel. 1 m/sec.^{2}, 1 kg weight.

TENTH-METER. 10^{-10} meter = 1 Angstrom.

THERM = small calorie = (obsolete).

THERMAL UNIT, BRITISH = the quantity of heat required to warm one pound of water at its temperature of maximum density one degree Fahrenheit = 252 gram-calories.

VOLT. The unit of electromotive force (e.m.f.). The international volt is "the electromotive force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of one international ampere. The value of the e.m.f. of the Weston Normal cell is taken as 1.0183 international volts at 20° C = 10^8 e.m.u. = 1/300 e.s.u. *See* page 80.

VOLT-AMPERE. Equivalent to Watt/Power factor.

WATT. The unit of electrical power = 10^7 units of power in the c.g.s. system. It is represented sufficiently well for practical use by the work done at the rate of one Joule per second.

Watts = volts × amperes = amperes^2 × ohms = volts^2/ohms (direct current or alternating current with no phase difference).

For conversion factors *see* page 251.

Watts × seconds = Joules.

WEBER. A name formerly given to the coulomb.

WORK in ergs = dynes × cm. Kinetic energy in ergs = grams × (cm/sec.)^2/2.

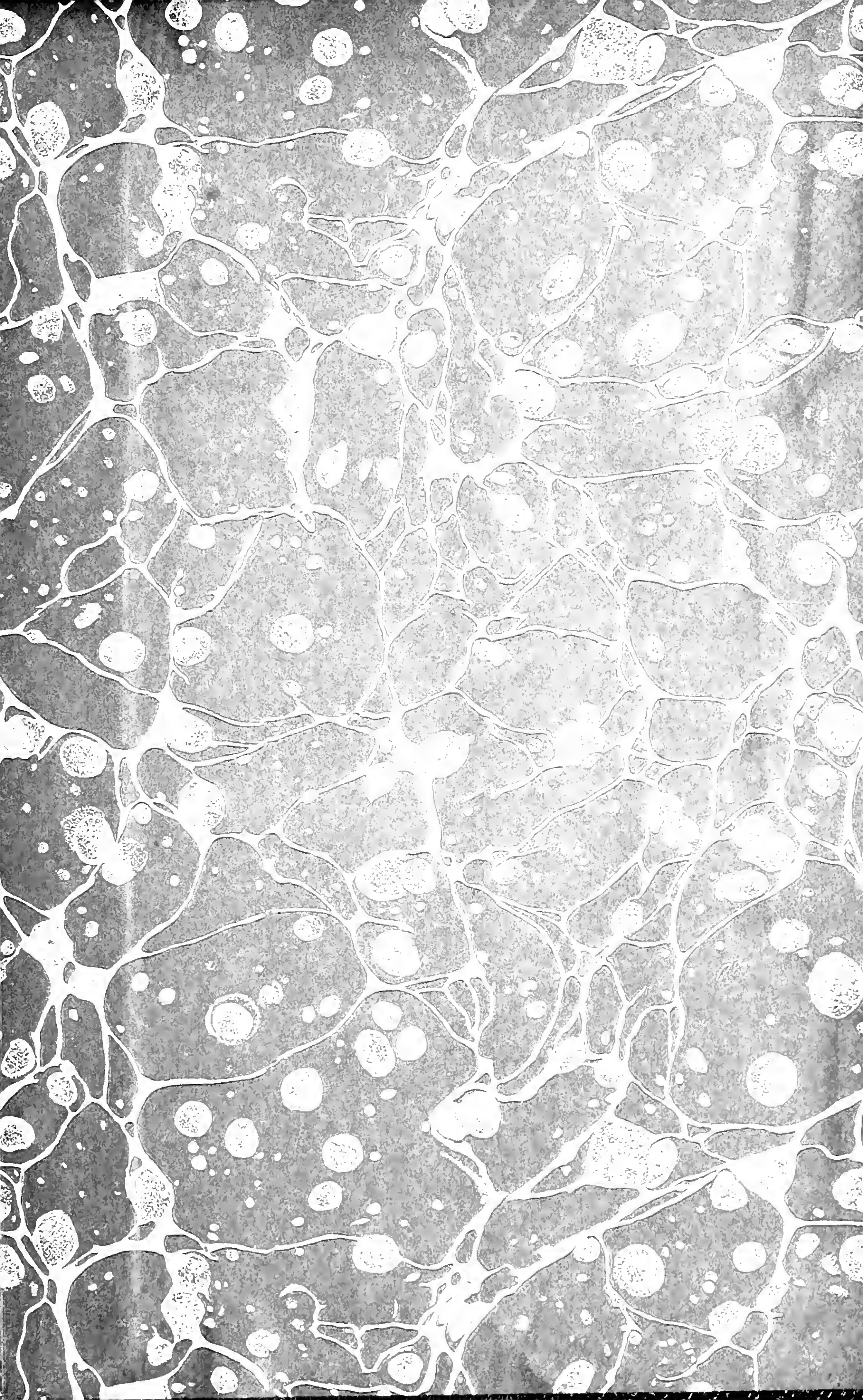
YEAR. *See* page 601.

Anomalistic year	= 365	days,	6	hours,	13	minutes,	48	seconds.
Sidereal "	= 365	"	6	"	9	"	9.314	"
Ordinary "	= 365	"	5	"	48	"	46 +	"
Tropical "	same as the ordinary year.							

INDEX

(References in parentheses marked I.C.T., followed by volume and page number, are to the first edition of the International Critical Tables.)

* Phenomenon too complex for insertion in book. See J. J. and G. P. Thomson, Conductivity of electricity through gases, 1928; K. T. Compton and Langmuir, Electrical discharge in gases, Rev. Mod. Phys., 2, 123, 1930.



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